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SCIENTIFIC INVENTORY MANAGEMENT FOR SHIPS OF THE UNITED STATES NAVY

by

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//
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A thesis submitted to the Faculty of The School of Government, Business, and International Affairs of The George Washington University in partial satisfaction of the requirements for the degree of Master of Business Administration

June 5, 1963

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CHAPTER I

INTRODUCTION

Much has been written about the role of the Supply Corps officer as an inventory manager, and many treatises have been written on inventory management improvement devices. However, most of these writings concern the inventory manager ashore--the inventory manager who works with large quantities of material in an impersonal manner. His functions as an inventory manager afloat, as the Supply Officer of a combatant ship of the United States Navy, have been largely neglected. It is in this capacity where he controls the material on the last stage of its journey from producer to end user, and it is in this capacity that he determines the requirements that, in the long run, determine the decisions made by his counterparts ashore.

The number and complexity of problems facing the afloat inventory manager may be less imposing than those plaguing supply managers ashore, but their solution is just as critical to the achievement of the operational readiness of the fleet.[1] On board destroyers, in particular, the job of the

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[1]A. J. Lenz, "Atlantic Destroyers Go SIM," Monthly Newsletter--Magazine of the Navy Supply Corps, Vol. XXV, No. 3 (March, 1962), p. 23.

Supply Officer has always been among the toughest and most challenging to which a Supply Corps officer can be assigned. The "greyhound" Navy is one of long and arduous hours required by the imposition of demanding standards of operational effectiveness and performance.

The sailing ships of Nelson's day were much more capable of casting off their dependence on land support than were World War II battleships. The increasing dependence of ships on fuels limited their ability to spend long periods away from land and increased the need for logistic planning and facilities. As ship designs improved and logistic facilities became waterborne, the requirement for far-flung coaling stations developed and navies once again became more dependent upon home-ports within the confines of their national boundaries. However, during World War II, the United States Navy was able to keep the carrier task force of the Fifth Fleet at sea for seventy-nine days through the use of transfer-at-sea replenishment techniques. This tremendous accomplishment had not been anticipated nor even thought possible at the beginning of hostilities. It was a plan developed to fit the needs of the times. This and other experiences of the war formed a firm foundation for the current operational doctrines of our deployed forces in the Mediterranean and Western Pacific operating areas. The effort that is required to keep these fleets mobile has advanced Navy

logistics to a position never before obtained.[1] An important aspect of this effort has been the development of shipboard inventories to meet the repair requirements of the highly complicated, sophisticated equipments installed in the ships.

Today's destroyer supply officer, for example, faces a challenge unknown to his predecessors--that of inventory management of some 17,000 line items of repair parts valued at nearly a quarter of a million dollars, and having an immeasurable impact on the operational readiness of his ship. The inventory management of repair parts has become big business for Supply Corps officers at sea. The quantity, value, and importance of the repair parts items now aboard destroyer-type ships equals or exceeds that of World War II light cruisers.[2] A guided missile frigate such as the USS Coontz (DLG-9) carries an inventory of 36,000 items worth $500,000, comparable to a wartime battleship. The management of these inventories is usually accompanied by inadequate personnel, both as to numbers and training for this exacting job, therefore requiring a higher degree of personal management by the Supply Officer. It is necessary for him to develop procedures which will allow him to delegate his authority with the assurance of obtaining the effectiveness for fulfillment

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[1] c.f., R.G. Iverson et al. "The Growth of a Rational System Approach to Naval Repair Parts Inventories: The Introduction of Military Essentiality" (unpublished research report, School of Government, Business and International Affairs, The George Washington University, Washington, D.C., January, 1962), pp. 3-4.

[2] Lenz, loc. cit.

of his responsibilities.

At the same time that the role of naval logistics has become more complicated and important to the operation of our fleets, new developments have taken place in the operations of this nation's business community. As an outgrowth of Frederick W. Taylor's scientific management approach at the beginning of the century has developed the field of the Management Sciences. Personnel studying applications of this branch of economic learning, primarily the operations research types, have found many areas for improvement of inventory control techniques in the business environment. Although many of the new techniques have been in existence for years, they have not been implemented very rapidly, and in fact, not much attention was given to them until after the second World War. These techniques have been adopted by the military inventory management systems for application to the colossal inventories which support our armed forces. Wider application is possible.

It is the thesis of this paper that these scientific inventory techniques are universal in application, and that the main reason they have not found wider acceptance is that they have been couched in mathematical terms, not readily understandable by the average business manager, be he military or civilian. This paper is an attempt to synthesize the scientific inventory management techniques which have been developed into a format that the Supply Officer of one of our Navy men-of-war can use to manage his inventories more effectively; a format or technique that he can use to assure

himself of a rational systematic approach to his whole inventory in order to meet his responsibilities for the operational effectiveness of his ship. Although certain standard procedures and requirements must be met, each ship has a different problem requiring individual initiative on the part of the shipboard Supply Officer.[1]

To convey an understanding of the applications of these techniques this paper makes an analogy of civilian or business inventories to military inventories in general and to shipboard inventories in particular. Similarly, the concept of scientific inventory management is developed from a business environment and applied to the military environment. Underlying all of our decisions is the constraint of the amount of money available to effect those decisions. This is universal.

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[1]Personal interview with Commander W. K. Woodard, Assistant Director, Fleet Operations Division, Bureau of Supplies and Accounts, Navy Department, Washington, D.C., October, 1962.

CHAPTER III

INVENTORIES GENERALIZED

Any discussion of inventory management should start with an examination of the purpose for maintaining inventories, because generally most inventories are looked upon as a necessary evil--as something to be kept to a minimum with a minimum investment of funds. The questions businessmen raise in connection with management and control of inventories are basically aimed at action, not at arriving at answers. The questions are stated, unsurprisingly, in the characteristic terms of decisions to be made: e.g., where shall we maintain how much stock? However, action questions are not enough by themselves. In order to get at the answers to these questions as a basis for taking action, it is necessary to back off and ask some rather different kinds of questions: Why do we have inventories? What affects the inventory balances we maintain? How do these effects take place? From these questions, a picture of the inventory problem can be built up, which shows the influence on inventories and costs of the various alternative decisions which management may ultimately want to consider.[1]

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[1] J.F. Magee, "Guides to Inventory Policy," Harvard Business Review Statistical Decision Series (Cambridge, Mass.: Harvard University Press, 1957), p. 160.

An inventory is a stock of goods held or stored for the purpose of future sale or production.[1] They constitute an alternative to production or procurement in the future. To have available one unit of product tomorrow, we may either produce (or purchase) it then, or produce (or purchase) it today and store it until tomorrow. The choice between the two procedures depends upon their relative profitability.[2] Inventories go further, however, and that is to buy time, and to decouple successive stages of production and distribution. They give the manager flexibility in his operations between one stage and the next, and reduce the interdependence of the different stages. When there is a perfect synchronization between receipts and production, and between production and sales, it may be possible to get along without inventories of raw materials and finished goods. But even if such perfect synchronization were possible, it is likely that it would be uneconomical.[3]

In the military the reasons for carrying inventories are similar. In a sense, time or a reduction in the interdependence of the echelons of the distribution system is being bought here too, but available funds are used also to buy more ready time for weapons systems instead of using the same funds to buy more

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[1]K.J. Arrow, S. Karlin, and H. Scarf, Studies in the Mathematical Theory of Inventory and Production (Stanford, Calif.: Stanford University Press, 1958), p. 18.

[2]Ibid., p. 19.

[3]T.M. Whitin, The Theory of Inventory Management (Princeton, N.J.: Princeton University Press, 1957), p. 84.

weapons or equipments. The purpose of any military supply system is to provide those spare parts and supplies required to maintain the equipments and personnel necessary for the performance of assigned missions. On the other hand, from Congress and other agencies reviewing budgets, there is an emphasis on conservation of available funds by keeping inventory levels as low as possible.

The question before inventory managers, then, is: How big should inventories be? The answer to this is obvious--they should be just big enough. But what is big enough? This question is made more difficult by the fact that each individual within a management group tends to think of inventories in isolation from other operations. In a civilian environment, the sales manager commonly says that the company must never make a customer wait; the production manager says there must be long manufacturing runs for lower costs and steady employment; the treasurer says that large inventories are draining off cash which could be used to make a profit. Such situations occur all the time. The task of all production planning, scheduling, or control functions, in fact, is to balance conflicting objectives such as those of minimum purchase or production cost, minimum inventory investment, minimum storage and distribution cost, and maximum service to customers.[1] This in itself poses problems, for it is impossible to choose that policy which simultaneously maximizes gain and minimizes cost, because there

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[1]Magee, loc. cit., p. 159.

is no such policy--maximum gain is infinitely large, and minimum cost is zero.[1]

This same parochialism of viewpoints occurs within the military environment: the Missile Officer wants his parts "now"; the shore-based Controller says that funds for inventories are limited. In addition, there is the very real factor of operational readiness of the forces to perform their assigned missions, as the frame of reference in which service to the customer is evaluated. If the equipments needed to perform the various missions are out of commission for lack of parts, the operational readiness is certainly adversely affected. However, it is obvious that it is economically impossible to stock all items which might be required in all places where they might be needed, which policy would be necessary for the customers to have all their requirements satisfied immediately all the time.

Composition of Inventories

An examination of the composition of inventories should be made with the definition of their purpose in mind. There are many different types of businesses with different materials, but their inventories can be categorized into five groups:[2] materials inventory, purchased parts inventory, supplies inventory, work in process, and finished goods inventory.

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[1] C.J. Hitch and R.N. McKean, The Economics of Defense in the Nuclear Age (Cambridge, Mass.: Harvard University Press, 1960), p. 165.

[2] R.N. Owens, Management of Industrial Enterprises (Homewood, Ill.: R.D. Irwin, Inc., 1953), p. 535.

Materials inventory is the stock of items which become part of the product manufactured. This category is sometimes called the raw materials inventory.

Purchased parts are fabricated items which are bought from other manufacturers in a finished or semi-finished state.

Supplies include those items which are used in manufacturing or associated processes, but are not a part of the product. Examples are rags, stationery, cleaning supplies, etc. These are handled in a separate category, because their costs are not assignable to a particular product, and are therefore considered a part of the plant overhead.

Work in process is the partially completed product in the factory in the process of manufacture, and is sometimes referred to as the "factory float."

Finished goods are the manufactured products in the form in which they will be sold to the customers.

While these categories are derived from an industrial source, they can be applied to any business, although they would not necessarily be expressed in the same terms. In a manufacturing business, the materials inventory, purchased parts inventory, and supplies inventory are combined in various mixes in the work in process stage, and are produced as the finished goods. It can be seen that in this particular frame of reference inventories are utilized to decouple the various stages of production and make them more independent of each other. Once the finished goods are produced they may be utilized in a similar manner to decouple the distribution

process from the factory to the consumer.

While the problems of a retail business differ from those of a manufacturing establishment, the techniques of inventory management, as well as the problems, are similar.

In the military services inventories consist of technical repair parts; common-use supplies; and functional goods, such as subsistence stocks, resale merchandise, petroleum products, medical supplies, etc.

Technical repair parts, by far the majority of items in the military supply systems, are those parts used to repair equipments in use in a military service. Most technical repair parts are peculiar to one equipment, although most manufacturers try to use their own parts in designing their own equipments, and a duplication is found in different equipments by the same manufacturer. There are also certain common-use items, such as electron tubes, that are universally used.[1]

Common-use supplies are general supplies not identifiable to a particular equipment, including the categories described in the civilian supplies inventory above. Certain common-use hardware, such as packing, gaskets, tools, etc., are included.

For the purpose of this paper technical repair parts and general supplies are separated from the other commodities as a subject of discussion. While they are all managed by similar techniques, the first two constitute the biggest problem from a

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[1] c.f., Iverson, et al., loc. cit., pp. 8-13.

management point of view, particularly to the sea-going inventory manager. In the Navy alone they constitute the largest number of items--1.2 million--as well as being the classes of items with widest application in terms of different ships or activities using the material. This does not minimize the importance of the other materials to the mission of the services, but they represent a small number of items susceptible to more precise manipulation than the hardware type material; for example, their requirements can be determined on the basis of number of flying or steaming hours, or the number of people on board.

Distribution System

It is not enough to say that business or the services have inventories to decouple stages of manufacture or to buy time. It is necessary to examine the systems for distribution of inventories to provide the service to the customer.

Business enterprises maintain inventories at the plant, at wholesale warehouses, and on retail shelves. These all may or may not be under one control or ownership, but until the goods are bought by the final consumer, they are distributed through this particular network. Although the particular structure will vary with the size of the company, volume of sales, or area of distribution of the product, it will generally follow the pattern described. The more numerous and varied are the echelons of inventory, the more complicated becomes the problem of inventory management. This aggregation

of activities introduces problems of redistributing assets between stocking activities, which is also an expensive proposition.[1] In this respect, the element of time required to move inventories from one echelon to another is a prime consideration, and one that partially determines the number of echelons required, but also, as Forrester points out, this time element has a multiplying effect on usage, causing disproportionate stock levels at higher echelons in the system.[2]

The military services have similar distribution systems and problems, but of even more complicated types. In the first place, the many different types of ships and planes and the myriad equipments installed in them require a large number of different items in the inventory; and in the second place, the world-wide dispersal of these operating elements of our forces requires a similar supporting dispersion of inventories.[3]

The Navy Supply System is predicated upon management of inventories by type or category of material in support of weapon systems. Most items in the inventory are centrally managed at Inventory Control Points, which are established by category of material, i.e., missile and ordnance, aviation, electronics, ships parts, general supplies, automotive and construction, subsistence, and fuel. Obviously, these

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[1] Whitin, loc. cit., p. 17.

[2] J.W. Forrester, "Industrial Dynamics," Harvard Business Review Statistical Decision Series, p. 73.

[3] c.f., U.S., Department of the Navy, Office of Naval Material, Navy Policy and Standards for Inventory Management, NAVEXOS P-1500, February, 1960, Chapter II.

categories have cross-applications in weapons systems, but there is more compatibility for the functions of inventory management by type of material than by end-use equipment. The synthesizing of the two concepts is accomplished by the weapon system managers, the bureaus of the Navy Department, who place their requirements upon and provide information by weapons system to the inventory managers, who distribute and buy material in support of these plans. (Without complicating the subject, some of the Inventory Control Points have dual functions: as inventory managers for their material, and as program managers, acting for the bureaus, to cross-fertilize the weapon system program requirements with other ICP's.)

The material is stocked at various supply installations around the country and overseas. The top echelon of the stocking system is the distribution points. There are large supply depots, the two major ones being at Oakland, California and Norfolk, Virginia. They serve two purposes. They act as wholesale stock points for the insurance items in the various inventories, and as immediate support activities for naval units and installations in their geographical area. This latter effort includes support of the fleet in the forward areas--the Mediterranean and Western Pacific. The next echelon consists of primary stock points. These are either smaller depots at fleet bases, or supply departments of naval shipyards and naval air stations. They provide direct support to fleet units in their area. The third echelon is the retail level, which consists of stocks maintained on board ships of the fleet

and at smaller shore installations for their own use.

The concept of central management requires the distribution points and primary stock points to report their usage, or issues, to the Inventory Control Points. This is performed almost entirely on a transaction or as occurring basis, utilizing, to a growing degree, rapid data transmission systems. The ICP's maintain records on EDP equipments for each item in the inventory; for example, the Naval Ordnance Supply Office controls approximately 140,000 items peculiar to navy ordnance and missile systems, and the Aviation Supply Office controls approximately 600,000 items peculiar to naval aircraft. These inventory management activities place orders, at the appropriate time, with many different manufacturers for delivery of material to the different stock points. A primary concept of Navy inventory management calls for delivery from manufacturer to as close to end-use as possible. In this respect the Navy does not use a wholesaler-retailer approach, and the central processing of usage information eliminates much of the multiplying effect referred to by Forrester.

The usage or demand that is reported by the reporting stock points to the ICP's is generated by requisitions placed by the end-user activities of the Navy: primarily the ships of the fleet.

Not all items in the inventory at the various echelons are centrally controlled. There are many items of readily available commercial material or insurance-type repair parts that either have insufficient Navy-wide demand or are

uneconomical from a procurement standpoint to manage centrally. These are referred to as decontrolled items, and are managed by each local stock activity, including ships.

Shipboard Inventories

Inventories aboard the ships of the Navy are an important aspect of the distribution system, and more than any other segment serve the basic purpose of inventories--to buy time. The development of the ability of the Navy to maintain itself at sea in a mobile condition has severed the umbilical cord between the ship and the shore-based support echelons. It is mandatory that ships be able to sustain themselves while operating as part of naval task forces or on independent duty.

When ships are operating, their equipments are operating; when the equipments are operating, parts are subjected to wearout and failures. In addition, the normal housekeeping functions performed by any small city must be performed, and this requires supplies. The problem in shipboard inventories is to determine what items to carry and how much.

It may be helpful to trace the progress, briefly, in ships' inventories from the well-known "repair part box" to the present integrated system.[1]

Until recently, repair parts placed on board ship were held in the custody of the department having primary interest in the particular equipment which the parts supported. This goes back to the basic military policy that each commander

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[1]Lenz, op. cit., p. 23.

should have control of his logistic support. The operations department held electronic spares; gunnery department, ordnance spares; and engineering maintained the stocks of machinery spares. Repair parts were stowed primarily in repair part boxes with a box of spares provided for each installed equipment or major component.

Each of these areas of support had the repair part boxes stocked in accordance with the requirements of the technical bureaus. Each bureau used a different medium for making its requirements known to the ship. The media were known as "Allowance Lists." They contained each of the bureaus' best estimate of the parts required to support a given equipment. The format differed for each technical bureau, but, generally, the basic information provided was similar.

Shipboard allowance lists are important as an effective tool for shipboard supply management. Of key importance is their effect on the endurance capability of the operating forces. They serve as guides for the accomplishment of the initial outfitting of newly commissioned ships, as technical documents as well as supply documents for inventory management afloat, and as our only available measure of a ship's supply readiness. Moreover, the criteria and policies which govern the construction of shipboard allowance lists have an extensive influence on many other actions of the supply system, from the shipboard level through the echelons to the bureaus and ICP's.[1]

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[1] Iverson et al., op. cit., p. 26.

Under the repair part box concept, however, many duplications of inventories existed. Many identical parts were used in different equipments, or even the same equipment located in different parts of the ship. Because of the lack of central inventory information, the duplicate availability of a part was not known, in most cases, when a part was lacking in a particular box for a particular equipment. Basically, there lacked a centralization of demand or usage information and item availability for parts being used within the ship as a whole.

Personnel of the operating departments having custody of the spare parts boxes maintained various forms of stock records, submitting their requirements for stock replenishments to the Supply Officer for procurement action. The Supply Officer had no inventory management or custody responsibilities. Inventory control, as exercised by the operating personnel, was basically "use one from the box--put one back in the box." In the hands of personnel whose primary interest and responsibility was the immediate repair of inoperative equipments, this system resulted in many inventory control service failures--the parts did not get replaced.[1]

As greater quantities of more complex equipments were placed aboard ships, the space requirements for the larger or more numerous repair part boxes exceeded the space available, especially in destroyers and submarines. Perhaps the most significant development from the point of view of its

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[1]Lenz, loc. cit.

far-reaching effect on current repair parts systems was discarding the repair part boxes in favor of centralized bin or drawer storage. The requirements determination, or usage data base, shifted from the individual unit to a grouping of like equipments. The foremost proponent of this approach was the Electronic Supply System. The duplications of items common to the needs of all electronic systems (plus supply supported equipments that were program supported by other ICP's), the space limitations, and the cost in terms of dollars all contributed to this development.[1] At the same time the conversion from box stowage to bin stowage was made, the custody of the material was transferred to the supply officer. For the junior officer on a destroyer this was an assumption of responsibilities of great magnitude.

To eliminate duplication even further, in 1956 the Coordinated Shipboard Allowance List (COSAL) Program was established.[2] The major objectives were to develop standard allowance list formats; centralize shipboard inventories for all materials; and to consolidate requirements.

The magnitude of the problems which existed and the scope of the afloat inventory manager's responsibilities has been multiplied in recent years, for a technological explosion has been occurring. New radio, sonar and radar equipments, not to mention new and sophisticated weapons systems have been

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[1]Iverson et al., loc. cit., p. 16.

[2]U.S., Department of the Navy, Office of the Chief of Naval Operations, OPNAV Instruction 4441.4 of 20 December 1956.

introduced into the fleet, and more are on the way. Ships constructed fifteen to eighteen years ago are being continually modernized by the removal of older, relatively simple equipments and replaced with new, vastly more complex gear.

As installed equipments have become more powerful and complex, there has been a commensurate growth in the number of repair parts to be carried on board to insure maximum support of the equipments. A typical destroyer now carries some 17,900 items valued at nearly $232,000. A guided missile frigate (DLG) carries about 36,000 items worth $500,000. A new Fleet Ballistic Missile submarine carries 25,000 items worth $1,500.000.

Inventories of this magnitude require a logical, systematic management system, which is understandable and usable by the afloat supply officer.

CHAPTER III

INVENTORIES ANALYZED

Basic Inventory Management Considerations

The management of inventories can be resolved into three basic considerations: what to stock; where to stock it; and the functions of inventory--how much to buy and when to buy it. The functions of inventory usually occupy the attention of the inventory manager.

The end result of any business is to sell a product. Therefore, the first consideration of what to stock in business inventories should be the finished goods and the anticipation of selling them. It is obvious that an entrepreneur is not going to invest money in an inventory, unless there is some reasonable anticipation of selling it at a profit within a reasonable period of time. As part of this consideration, the entrepreneur will take into account the risk involved in not selling the product and the loss of the money tied up in inventory. Whether he uses a rational, structured decision-making process, or whether he trusts to intuition, he will balance these factors against each other. Similar considerations are made regarding the raw materials inventory and the work in process inventory in manufacturing operations. In these cases the anticipation of sale is related to anticipation of production orders on the

plant for the materials that go into the finished product. It is obvious that regardless of the type of product or business, some decision must be made before an item is carried in inventory, and that decision will balance cost of carrying the item versus the benefits to be gained from having it available when wanted.

The problem of selecting items for the military inventory is analogous in terms of anticipated usage. The majority of the items in the inventory, as stated, consists of technical repair parts. These are selected either because it is anticipated that parts will fail, requiring replacement with a certain degree of repetition, or because they are what is referred to as insurance items, which, in the case of failure, would adversely affect the operational readiness of the service because of the length of time required to procure the part, and the time that the parent equipment would be out of commission. Consumable supplies are generally selected for inventories because of their utility for different purposes and because there is a repetitive need for the item.[1]

In both business inventories and military inventories, the distribution system, or where to stock material, is not an easily determined factor. For best service, material should be stocked near the point of need, but the fact that inventory effectiveness is generally measured by turnover of inventory, and the parochial viewpoints of the different members of

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[1]Office of Naval Material, loc. cit., p. 3-1.

management often combine to make the decision difficult.

Analysis of the Functions of Inventories

The functions of inventory--how much to buy and when to buy it--are basic to any inventory, whether it be purchased parts, manufactured parts, work in process, or military parts or supplies.

Any inventory may be divided into two parts. The first is the element that has as its prime purpose the filling of normally anticipated usage. It is known as working stock, and is sometimes referred to as "lot size" stock. It is created by the quantities that are ordered, and can be seen when the order arrives as a finite quantity of goods.

Basically, this inventory arrives as an order quantity is used up and is replaced by another order quantity. Everything else being equal, the activity of this inventory can be pictured as a saw-toothed diagram, as shown in Figure 1. Goods arrive, are depleted, are reordered at a reorder point which depends upon usage and leadtime, are replenished by the new order, and the cycle starts again.[1] As can be seen from this diagram, average working inventory amounts to about half of the order quantity and is independent of the number of times per year the cycle is repeated.

The inventory pictured in Figure 1 represents an ideal

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[1]W.E. Welch, Tested Scientific Inventory Control (Greenwich, Conn.: Management Publishing Corp., 1958), p. 23.

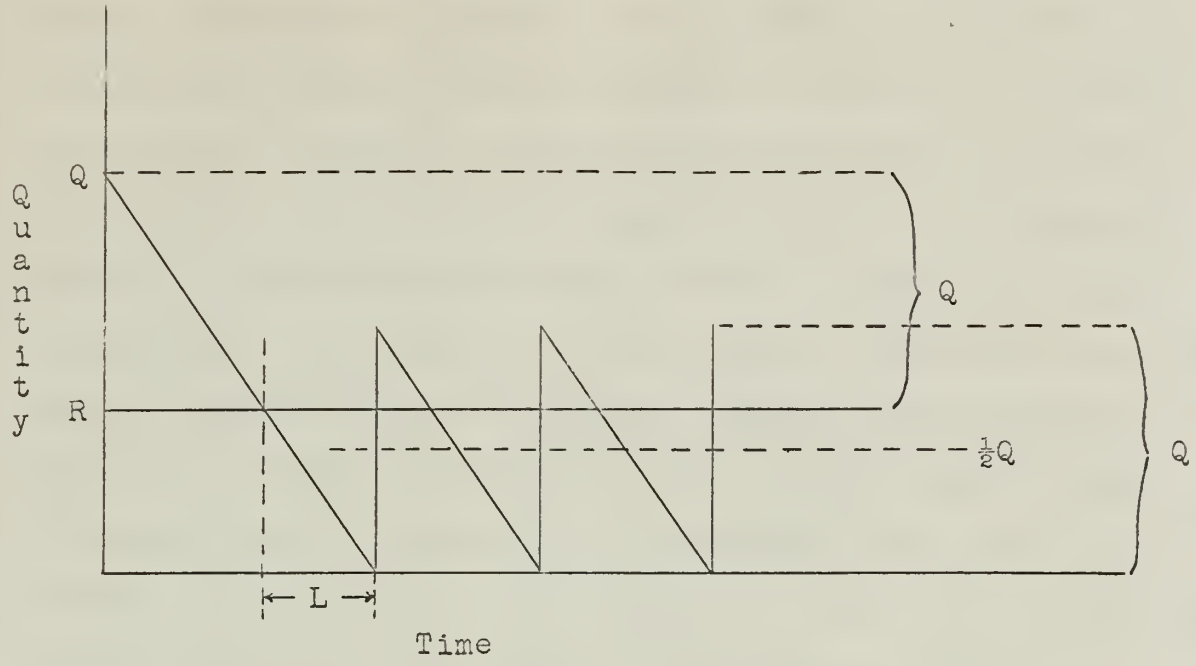

Fig. 1.--Functions of Pure Inventory

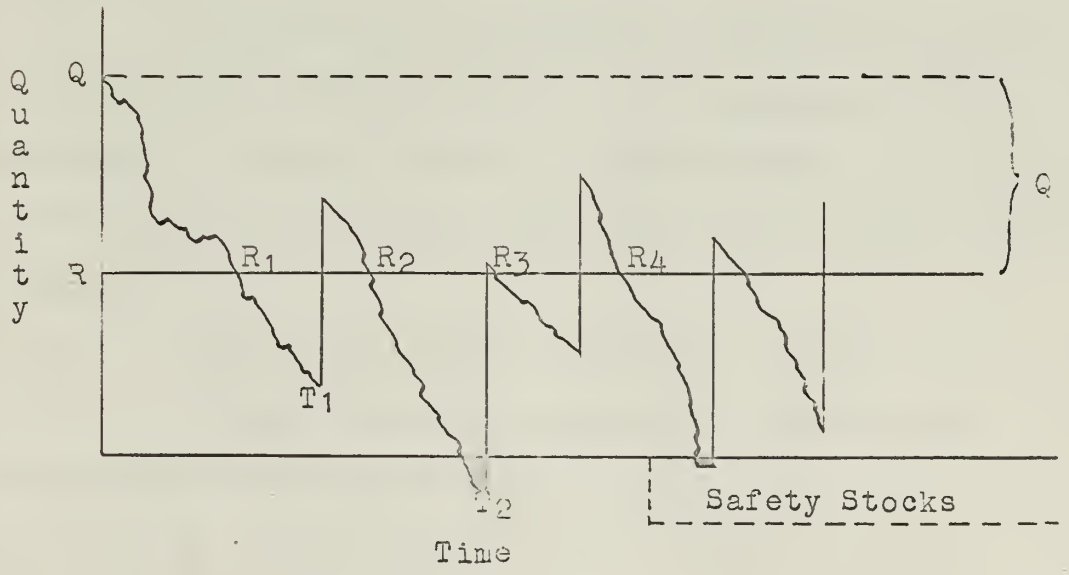

Fig. 2.--Functions of Actual Inventory

inventory, and in this pure form consists solely of working stocks. Material is consumed at a constant rate, and at point R, called the reorder point, the amount of the order quantity, Q, is placed on order. Material continues to be used during time period L, which is the leadtime (whether it be purchase leadtime, manufacturing leadtime, assembly leadtime, or some combination). The leadtime is the length of time from which the need for reorder is first noticed; through the preparation of the order, or paper processing time; through manufacturing or assembly time; and delivery time to the point where the material is put in stock, and entered on the stock records. The reorder point, R, is the quantity of material required to satisfy consumption during this leadtime period. The terms R and Q are commonly used terms to denote their respective concepts of or effects on working stock and are used throughout this paper.

As a matter of practicality the amount ordered may not be a quantity greater than R. The reasons for this may be economic or perhaps because of uncertainties in requirements. As a result, orders are placed when the following situation occurs:

Quantity on hand + Quantity on order = or is less than
Reorder Point + Obligations or Backorders.

Conceptually, the saw-toothed diagram in Figure 1 would operate in the same manner, except that R would be above the amount of stock on hand at any one time. If Dues are added, the amount on hand plus on order would just reach R when each Q is ordered.

If usage and leadtime would just behave the same way all the time, the problems of inventory management would be greatly reduced. Reorders would be placed at a reorder point equal to the leadtime multiplied by the usage. The new order would arrive just as the last unit of the old stock was issued, and the problems would be pretty much confined to the determination of the order quantities.

Unfortunately, the facts of life are different! Leadtime, or usage, or both will vary. Actual results would look something like Figure 2; the new order would arrive ahead of need some of the time and after the need in others, due to fluctuations in demand during leadtime, and in some cases due to variations in leadtime. As a matter of fact, it would be expected that one would happen as often as the other, and the inventory would fail, or stockouts would occur in one out of two orders (this results from using average demands; in an average half of the occurrences are greater than the average, and half are less). The probability of 50% stockouts when there is no safety factor in the reorder point is an important concept. Being out of stock for even a short time every other order is not usually considered satisfactory inventory performance. It is therefore necessary to reorder at some point in time prior to the point one would like to, so that the order will arrive before the last unit of the old stock is issued out. The effect of this action is to increase stock levels.

This introduces the second element of any inventory--

safety or fluctuation stocks. The amount of safety stock is the number of units by which the reorder point is advanced ahead of what is normally expected to be needed, in an attempt to reduce the probability of stockout. This is illustrated in Figure 2. At point R_2 quantity Q is ordered, which arrives at time T_2, after there has been a need for material, but no stocks to issue. In the second case, safety stocks have been created, so that when Q is ordered at R4 and the material is delayed in receipt or the usage has increased, a stockout condition is not encountered, but rather part of the safety stocks are issued.

The total average inventory on hand, then, is the sum of the average working inventory (referred to as $\frac{1}{2}Q$), and all of the safety stock. It becomes very apparent that safety stock is an important part of the total inventory, and that it is not easily identified. Working inventory is quite easily identifiable; one need only check on order quantity practices to know the inventory that is created by orders. On the other hand, to identify safety stock, one must go to some record which will show what was on hand at the time each order was received.[1] This is more difficult.

The important thing is that safety stock is created to reduce the probability of stockout during leadtime to less than 50%; how much less is one of the main problems of inventory management.

The principal causes of inventories, then, are expected

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[1] Welch, loc. cit., p. 25.

changes (anticipation) in cost or demand functions; discontinuities in rates of ordering, production, and sales; and the uncertainty of demand.[1] The problem of discontinuities in demand has special effects on military inventories.

Demand Problems in Military Inventories

Demand is the most important and difficult element to consider in making good inventory management decisions. The military supply business is plagued with the problem that in almost all classes of material most of the items have low demand rates and highly unpredictable demand patterns. This particular problem is recognized by Hitch:[2]

> Out of 100,000 spares allocated as repair parts for a modern bomber, only 50% may be used at all, and then only 10% used only at depots (large repair facility). Demand for parts at one base may not necessarily be predictable for spares used at others. About 10 to 30% of spares used on modern aircraft are peculiar to that model and configuration, and at a two-wing bomber base, about half of the spare parts for which demands are realized might be at a rate of lower than ten a year. In most cases, demands are lower. Actual variations from month to month are greater when average demand is low. Such a variation leaves the mean with little significance. The old military concept of so many weeks of supply as a measurement of stocks, while suitable for, say the cavalry with horses to feed, may be most dangerous when applied to modern aircraft.

Figure 3 is an illustration of observed failure rates for spares for the Atlas ICBM guidance system.[3] This group

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[1]Whitin, loc. cit., p. 85.

[2]Hitch and McKean, loc. cit., p. 272.

[3]H.W. Karr, Report on Phase A, Nose Cone Material Management Study, Technical Military Planning Operation Report R58-TMP-21 (Santa Barbara, Calif.: General Electric Co., 20 June 1958), p. 4.

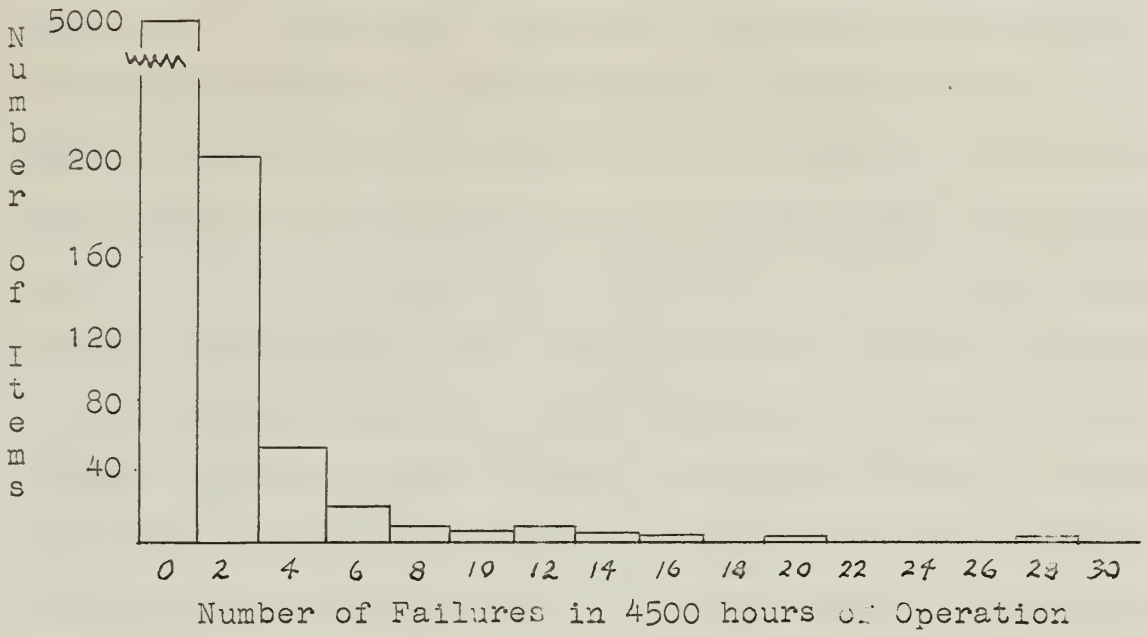

Fig. 3.--Distribution of Observed Failures for Atlas ICBM Guidance System Spares

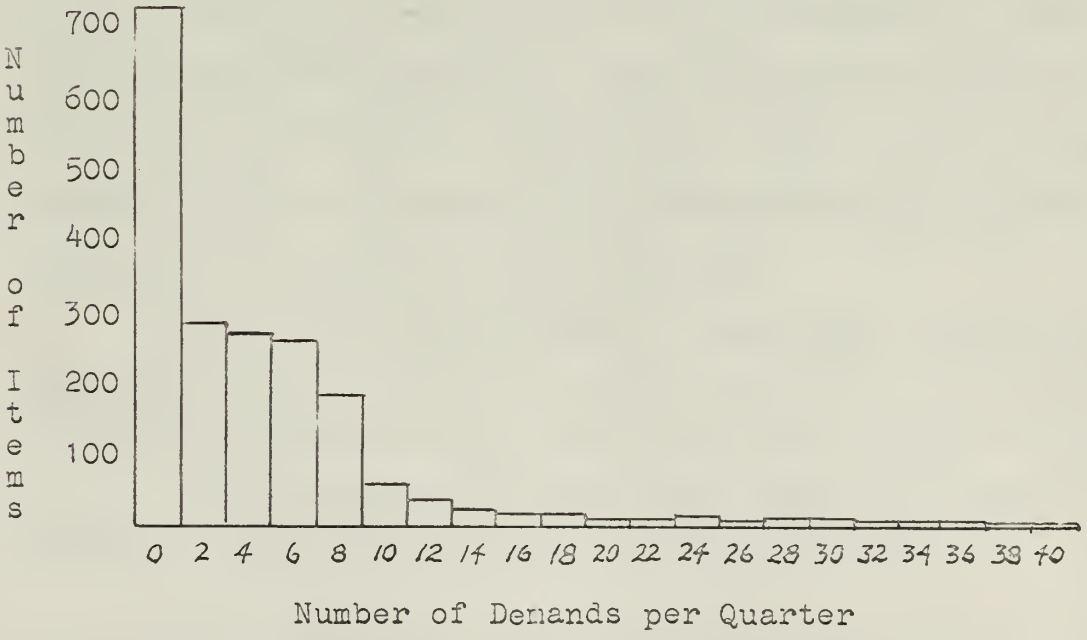

Fig. 4.--Distribution of Observed Demands for GA Fraction Material at NSC, San Diego, California

consisted of about 5,500 items for which demand was studied over a ten-month period. It is seen that about 5,000 items experienced no demand; about 200 had one demand, which is a mean demand of .1 per month; and about ten items had demands for ten, which is a mean of 1 per month. The natural reaction to this might be that it is to be expected, since a high degree of reliability should have been designed into an ICBM nose cone. However, the same source refers to a similar pattern in spares applicable to the B-47 aircraft, and the Navy has a similar situation in submarine spares.[1] Recognizing that these are all spare parts, refer to Figure 4. The profile of submarine repair parts is practically identical to this, yet the profile presented in this illustration was taken from a study of general supplies at the Naval Supply Center, San Diego, California, in connection with management of decontrolled material.[2] Here it is seen that out of 3,463 items over a three-year period, 736 or 21% experienced demands of one or less, 848 or 53% had demands of less than ten per quarter. This is in a category of material which is supposed to be characterized by repetitive demands, or so-called fast-moving items.

It is this preponderance of items with very low demand rates that causes most of the difficulty in supply management

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[1]U.S., Department of the Navy, Bureau of Supplies and Accounts, Introduction to Variable Stock Levels (June, 1960), p. 4-1.

[2]R.F. McIntosh, Improvement of Local Supply Decision Rules at NSC, San Diego, Report PRC-132 (Santa Monica, Calif.: Planning Research Corp., 1 October 1959), p. 3.

in the armed forces. In addition to comprising most of the inventory, slow-moving items also present a high variability in demand. Relative variability of demands is determined by measuring demand occurrences as a percentage of average demand. While variability at high demand rates is greater in absolute terms, variability at low demand rates is greater in relative terms. For an item with a mean demand of one per quarter, a demand of six at one time (not an unusual occurrence) would be 600% of the average, while for an item with a mean demand of .1 per quarter, a demand of three at one time (once again, not an unusual thing) would be 3,000% of the average.[1] Methods of coping with this problem are discussed under the concept of probability theory.

Money Value Analysis

There is one general characteristic of most inventories which is of paramount importance, but is one that is often overlooked. It suggests a plan for managers in their approach to inventories. This characteristic is that some items of any inventory have a much higher annual dollar usage than others, which causes a concentration of dollar usage in a relatively small percentage of the total items. Richmond suggests that 10% of the items may contain 75% of the money value of annual usage; 25% of the items 95% of the money value.[2] The

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[1] Bureau of Supplies and Accounts, loc. cit., p. 4-4.

[2] H.J. Richmond, "Streamlined Inventory Control and Stabilized Production Planning," The Controller, Vol. 24, No. 4, p. 162.

corollary, of course, is that 75% of the items represent only 5% of the dollar usage. Figure 5 portrays the effect of this characteristic.

This phenomenon of inventories is applicable to all types of inventories: spare parts, general supplies, or commercial inventories; although the ratios may differ from those suggested above, they are generally in the same "ball-park." The first step in any inventory study should be to take a large enough sample to determine the character of the inventory with respect to this usage-value of distribution. It is important, because it is the key to the amount of effort and money that should be spent in the control of different items in the inventory. Obviously, much more attention should be given to high value items than low value, and in effect the low value items, because of the relatively little importance in dollar usage, can be given pretty much a "broad brush" approach in applying management techniques. As stated previously, the main constraint on management of inventories, as well as any other decision, is the dollar constraint of limited funds available for various programs.

The general approach to inventory management that is suggested by this is obviously selected value management. This has been referred to by the General Electric Company as the A-B-C system. In Figure 5, the small number of items contributing to 75% of the dollar usage are labeled A; the medium value items, B; and low value, C.

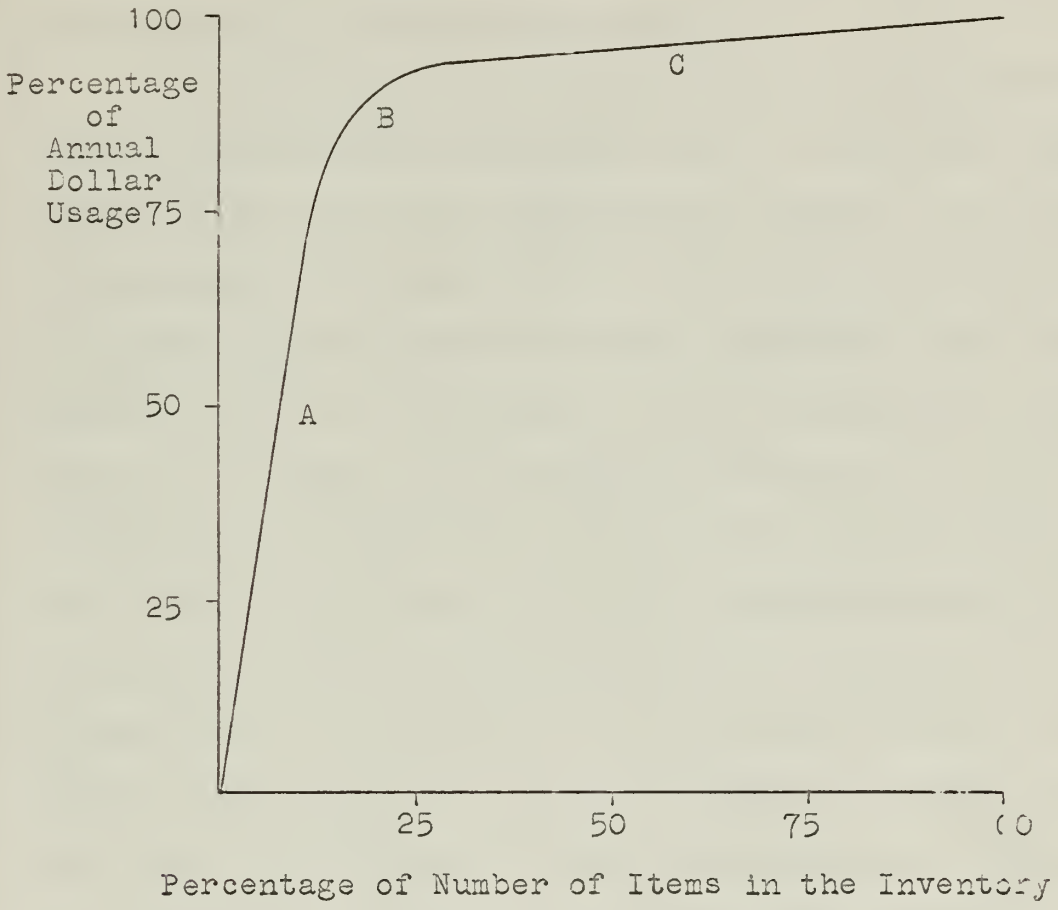

Fig. 5.--Relationship of Number of Items in Inventory to Total Annual Dollar Usage

Shipboard Inventories--The Problem Isolated

The problem of what to stock aboard ship is one coming under the cognizance of the Chief, Bureau of Ships and Chief, Bureau of Naval Weapons, who are responsible for the support of the equipments installed aboard ship.[1]

The stockage of parts on a ship of the United States Navy is accomplished through the COSAL. There is a separate COSAL for each ship for each type of material. Each of the COSALs consists of three parts: Part One is an index of all equipments supported by that COSAL, including those that are supply supported, in response to the requirements levied by the Chief of the Bureau on the program support ICP: Part Two consists of Allowance Parts Lists, one for each equipment. This serves two purposes--one is an identification aid to the technician, since it identifies parts to equipment drawing designations, and the other is an allowance of parts required to support that equipment or that component of a larger equipment. Part Three is a listing in stock number order of all repair parts allowed on board to support the equipments listed in Part One.

Obviously the heart of the accuracy of the allowance rests in the Allowance Parts List. Repair parts are placed on ships primarily to serve the needs of the ship on which they are loaded.[2]

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[1]U.S., Department of the Navy, Bureau of Supplies and Accounts, BUSANDA Manual, Para. 31001.

[2]Lenz, op. cit., p. 27.

The question is: Which parts will fail? Which will fail most often? And which parts are most important to the security of the nation, as represented by that ship? The answers are generally obtainable (but not always sought) if the system is a few years old. Data on parts usage can be projected mathematically into answers which tell now much to stock, but on new equipments "technical judgment" is relied upon. This is where engineering and planning specialists venture into the realm of intuition--a realm peopled by the bureaus, fleet representatives, ICP technicians, and manufacturers specialists.[1]

An Allowance Parts List is made up at the time an equipment or component of an equipment is first purchased for installation in the fleet. It is an engineer's estimate, supplemented by varying quantities of actual usage data and experience, of what repair parts should be carried by the ship to satisfy the most likely repair part needs of the equipment. The APL cannot provide an allowance for every possible repair part item which might be required by the ship. It is not intended to do so, for neither storage space on the ship nor funds available would permit carrying in stock every item which might conceivably fail. However, it has been shown that an APL may not only omit items required to satisfy unusual, random demands, but it also may not allow items on which repetitive

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[1]J.J. Tamalavage, "More Bang for the Buck," Monthly Newsletter--Magazine of the Navy Supply Corps, Vol. XXV, No. 6 (June, 1962), p. 16.

demands are experienced.[1] This may occur because of the engineering estimate aspect of requirement determinations, or because imperfections in manufacture, installation or maintenance may result in unusual or repetitive demands aboard a given ship.

As an example, in the Pacific Fleet all guided missile frigates were placed in Destroyer Squadron 15 for the first year of commissioning. These ships operated under basically the same conditions, had the same equipments installed, and in fact, two were built by the same builder. Each of the ships had different problem areas: one in missile fire control; another in the engineering plant; and yet another in the ship's radar installation. Yet all had the same allowances of repair parts for these equipments. As a result of situations such as this, each ship is required, in effect, to develop its own allowances based on failures or usage that may occur. For the Polaris program, a computer method of assembling demand for each ship and revising allowances for each ship has been developed.[2]

The decision of where to stock the material, with reference to shipboard inventories, is tied into the decision regarding what to stock. Usage data refinement is helpful, but there is another element that enters into the "technical judgment" or intuitive determinations made, and that is

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[1]Lenz, loc. cit., p. 26.

[2]Personal interview with Cdr. W.K. Woodard, Washington, D.C., October, 1962.

regarding insurance items. This category consists of items that do not have any anticipated repetitive demand, but are sufficiently essential to the operation of the equipment as to warrant their stocking as insurance against the possibility of failure. Stocking of insurance items falls into two categories: stocking aboard ship or stocking in the supply system. In both cases a rationalization is made of procurement lead time against necessity for the item.

Usage data for shipboard inventory management is an integral part of the functions of inventory--the how-much-and-when-to-order considerations. For the Supply Officer afloat this is his main problem. Recognizing the tremendous growth in the workload and importance of the function of repair parts management in destroyers, and in anticipation of almost certain future growth, in September, 1960 a study was made of this area in the ships under the control of Commander, Destroyers, United States Atlantic Fleet. It soon became apparent that inventory management afloat was not optimum in quality or efficiency, and that the destroyer inventory manager was not always making fullest use of the materials made available to him by the inventory manager ashore. This study revealed the need for detailed procedures governing the conduct of operations in this vital area. Hard-pressed destroyer Supply Officers had neither the time nor the experience to develop their own procedures. The frequent change of supply officers and key enlisted personnel produced an endless variety of systems and procedures lacking in consistency and continuity and often failing to

achieve the desired objectives. Analysis of afloat inventory management revealed that all destroyer-type ships faced substantially the same problems.[1] These problems are not limited to destroyer-type ships, but because of the greater number of destroyers and the relative inexperience of their personnel cause more problems.

The guide lines that are published for the supply officer afloat use the same general terms that have been discussed previously in the commercial or general environment. Unfortunately, the guidance is general, and does little, other than place the responsibility for "effective" inventory management on the supply officer of each ship.[2] The function, Q, is referred to as the operating level of supply--that which is required to sustain operations between requisition or arrival of successive shipment. The safety level is described in the same general terms, and the reorder level also corresponds to the situation as described, i.e., leadtime plus safety level.

The Supply Officer is made responsible for maintaining stock within the limits of the operating plans of the ship,[3] and further states that he will establish high and low limits (order point and order quantity) for all items except those with an allowance list quantity of less than two. The principle purpose of these shipboard inventories, in the terms we have used, is to buy time. The time that is bought is the ability of the ship to

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[1]Lenz, loc. cit., p. 24.

[2]BUSANDA Manual, para. 36000. [3]Ibid., para. 33016-2.

operate for specified periods of time. This is referred to as endurance levels. The Chief of Naval Operations and the Fleet Commanders prescribe stockage objectives in terms of endurance. In principle, ships should always have sufficient supplies on board to operate without replenishment for a period equal to the stockage objective as stipulated.[1] At each replenishment opportunity, ships are required to load to capacity. Operating schedules for ships are planned so that the replenishment opportunity will normally be afforded prior to the time supplies on board reach the safety level. In other words, a procurement lead time is set for ships. Unfortunately, this is an area of various interpretations. The fleets operate within them, but allowance lists are constructed on different endurance concepts. Ordnance parts are allowed for a 7½-month period; electronic parts for one year in the case of insurance items and three months for repetitive use items; and ships machinery parts for 4,000 operating hours or one year.[2]

Lack of standardization of procedures on a rational, logical basis is further complicated by the Supply Operations Assistance Program. This program involves off-loading, identification, inventory, remarking, removal of excesses, requisition of deficiencies, and re-stowage of all repair part

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[1] Ibid., para. 31041.

[2] Personal interview with Mr. J. Gumenick, Allowance and Load List Section, Material Management Branch, Bureau of Supplies and Accounts, Navy Department, Washington, D.C., March, 1963.

items at the time a ship goes through its shipyard overhaul.[1] In the Atlantic Fleet determination of excesses and deficiencies is based on a twenty-four-month usage quantity,[2] evidently because this is the period of time between overhauls. In the Pacific Fleet, shortages are based on one-year usage and excesses on two-years usage.[3]

It can be seen that the rules governing the timing and quantities involved in replenishment actions are confusing and difficult to audit. While it is generally desirable that there be no withdrawal of material from storeroom stocks without timely replacement, it is not desirable that the "use one--order one" procedures be followed without exception. The result of the latter policy would be, in the case of some fast-moving items, constant requisitioning actions for very small quantities. Consequently, both the ship and the shore echelons would be burdened with an unnecessarily large volume of requisitions to be processed. Procurement actions can be deferred and requisitioning actions saved, only by postponing replenishments on those items experiencing a high frequency of demand.[4]

Before leaving the area of the functions of inventory, two inconsistencies should be indicated. Although a stage is

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[1]Lenz, loc. cit., p. 26.

[2]U.S., Commander in Chief, Atlantic Fleet, CINCLANTFLT Instruction P4441.6, p. I-30.

[3]U.S., Commander in Chief, Pacific Fleet, CINCPACFLT Instruction 4441.4, p. 3-3.

[4]Lenz, loc. cit., p. 27.

set for determination of working stocks, the definition of endurance levels as prescribed by the fleet commanders and the period between replenishment opportunities is not the same. In addition, different items have different usage rates, thereby requiring different replenishment frequencies. Therefore, the question of how much to order and when to order it is still open to interpretation. Some items, in other words, do not require replenishment each replenishment opportunity. If a two-year usage quantity is on board it would not be ordered every three months.

The matter of demand variations has been reiterated by the study of the destroyer inventory management. In this case it was found that during a three-year period, 85% of the items on the allowance list do not experience demands. In addition, it was learned that only about 2% of the items allowed on board experience repetitive demands. The demands for these few items represented about 50% of the issues from stock.[1] Although dollar values were not applied to this particular analysis, it is apparent that the ABC structure would be portrayed.

Based on this, the Atlantic Fleet Destroyer Force instituted a Selective Item Management program, wherein the fast-moving items were segregated for individual management. Fast-moving items were defined as those with three or more demands in the period between shipyard overhauls, i.e., since the last SOAP processing.[2]

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[1] Ibid., p. 25. [2] Ibid., p. 23.

CHAPTER IV

A CONCEPT--SCIENTIFIC INVENTORY CONTROL

Statistical Decision Theory

Just before and during World War II a new concept began to emerge--the concept of Statistical Decision Theory. Not only was this new concept comprehensive enough to include all that is currently covered in the subject of statistics, but in addition, it involved ideas from other areas, such as the theory of games, cost accounting, information theory, logic, and economics.

Consequently, the name "statistical decision" is something of a misnomer. Many people other than statisticians have contributed important ideas. The statisticians arrived on the scene rather late, and more or less accidentally. They translated the existing ideas into statistical terms, added some ideas of their own, and then assembled all of these concepts into an integrated mechanism for making decisions. This decision machine has already been applied to such diverse areas as military strategy and betting on horses.

The main reason why many of the repercussions of statistical decision have not been felt is that publications on the subject are written for fellow specialists; even they sometimes have difficulty understanding them. It may take twenty years before these ideas reach other scientists in a

comprehensible form and even longer before they are taught to students. Specific techniques in cookbook form may be transmitted more rapidly, but the ideas diffuse slowly.[1]

In the specific area of inventory control this is probably more true than in those areas of management peopled by persons with engineering or mathematical backgrounds. It is the personal observation of the writer that as soon as a group of complex mathematical expressions is introduced to a group of non-mathematician inventory managers, there is an immediate resistance to the entire concept, promoted by the feeling that what cannot be readily understood cannot be worth knowing. This reaction probably holds true for application of the entire field of operations research.

The expression of concepts in mathematical terms does not require the expressions necessarily to be specified quantitatively. It is the interrelation of factors that is important. As Ansher stated:[2]

> The intellectual issue to be grasped firmly is the necessity for distinguishing between quantitative specificity, on the one side, and accuracy in the sense of identity with true value on the other. The language of mathematics differs from the language of words not because it is more accurate, but because it is more manipulatable. It invites comparisons not invited by verbal statement; and leads to more thoroughly documented conclusions.

A concept not appreciated by operating personnel is

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[1]Irwin D.J. Bross, Design for Decision (New York: The MacMillan Co., 1953), p. 2.

[2]Melvin Ansher, "Price Tags for Business Policies," Harvard Business Review, Vol. 38, No. 1, p. 77.

that even when certain of the factors are specified, the quantification does not have to be precise. Not understanding this, the entire qualitative concept is rejected. Qualitative judgments made by management can be quantified under pressure, and need not be accurate to be valuable. One analysis of production scheduling demonstrated that cost errors of a factor of two produced costs only 11% higher than would have been incurred with correct estimates of costs.[1] This allows considerable leeway in estimation of factors (or parameters), and yet provides for substantiated decisions.

As important as anything else in the field of statistical decision theory is the application of economics. It is the recognition of the fact that there are underlying values to all decisions. This is certainly apparent in the Department of Defense today. In developing alternative solutions to problems, the impact of the defense budget on the national income and gross national product requires the maximum utilization and optimum management of our resources--men, material, and money. It is a process of economic trade-offs; decisions are now being made on what to buy and how much to buy on the basis of a massive exercise in operations research. Operations research has been used often before, but only in the lower echelons of the individual services, and not as the prime basis for overall DOD determination of force levels.[2]

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[1] Ibid., p. 71.

[2] "Defense Budget Gets Unified for the First Time," Business Week, February 3, 1962, p. 76.

It is axiomatic that we recognize that resources are always limited in comparison with our wants, always constraining our action. If they did not, we could do everything and there would be no problem of choosing preferred courses of action. We should, therefore, inquire into the constraints that exist.[1]

Too often the impression is given that the economic approach in Washington is an attempt to put a definite price tag on all factors bearing on decisions, in order to arrive at optimum solutions. This is partially true; it is an attempt to quantify, but quantitative economic analysis cannot determine optimum solutions in generally acceptable ways all the time. However, it forces the manager to make a choice.[2] It is recognized that there are uncertainties in any decision, as well as incommensurables or those consequences of alternatives that cannot be readily translated into the common denominator being used, i.e., dollars.[3] The important thing is that both uncertainties and incommensurables should not be ignored, for they have a bearing on the problem and should be considered intuitively, if nothing else.[4]

The whole point in this discussion of decision theory is to stress the fact that decisions can be structured, and that quantification, while it need not be precise, helps define the problem and alternatives involved, and improves the manager's

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[1]Hitch and McKean, op. cit., p. 23.

[2]Ibid., p. 217.

[3]Ibid., p. 182.

[4]Ibid., p. 193.

conceptual capability--the ability to see the "big picture." With this, decisions that are made will be more rational and will be better substantiated.

Scientific Inventory Control

Scientific inventory control is a concept, embodying mathematical techniques as tools to manage inventories in an economical manner. It is a part of statistical decision theory and is a synthesis of economic decision theory and probability theory.

The field of inventory management has proved to be a desirable field for drawing together the interests of people of widely divergent backgrounds. Because of its fundamental importance in business, management is willing to cooperate in providing descriptive data and in experimenting with the application of new theoretical models. At the same time, the problems involved have been of such a nature as to engross the attention of leading scientists in the fields of economics and statistics. The issues involved have been susceptible to approaches that run the gamut from extremely simple to highly developed abstract models.[1]

Most studies in the area of inventory control have concentrated on the lot size and safety allowance aspects, as indeed, these are the most significant areas. Recently, though, linear and dynamic programming and servo-mechanism techniques have been introduced. Linear programming is applied mainly to

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[1]Whitin, op. cit., p. 231.

situations with important seasonal fluctuations in demand from period to period in an effort to reduce the fluctuations in production and optimize the reduced overtime costs with the increased inventory carrying costs. This has applications to and is being used on the redistribution of material within the multi-structural inventory distribution system of the Navy.[1]

Servo-mechanism approaches have application to the sporadic and fluctuating demand problem. It is based upon estimating usage patterns and using the feedback of actual usage to modify the prediction. It is generally comparable to the quality control techniques of using standard deviations around the mean, and gives the ability to adjust operations to actual conditions.[2]

The first lot size formula was presented in 1959,[3] but the introduction of these techniques is progressing at a relatively slow rate. As Melnitzky says,[4]

> The aborigine knew nothing about inventory control, and quite possibly his 20th century corporate counterpart is equally unenlightened. The changeover from inventory to inventory control bears no date. Some concerns plunged into the healthful waters of scientific management of inventories well before the first World War; others are still on the shore contemplating the advisability of wetting their toes.

Several factors account for the transition to scientific inventory control from a liquidity preference approach. First,

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[1] A.J. Clark and H. Scarf, Optimal Policies for a Multi-Echelon Inventory Problem, Report PRC-113 (Santa Monica, Calif.: Planning Research Corp., July 10, 1959).

[2] Whitin, loc. cit., p. 236. [3] Ibid., p. 213.

[4] B. Melnitsky, Management of Industrial Inventory (New York: McGraw-Hill Book Co., 1951), p. 3.

the increasing size of business establishments makes operations more difficult; second, management personnel have had more business training and are more aware of the ramifications of inventory management; and third, there is an increasing emphasis on having engineers in business to give a scientific approach to management in general.[1]

The management of inventories has been frequently treated as an intuitive process in which management must rely on experienced requisitioners with a "feel" for the problem in order to interpret properly broad directives. Lacking a more suitable tool, these directives take the form of: "Use your best judgment in the determination of order quantities, but watch your total inventory," and "Arrange the timing of your purchases and your manufacture to avoid interruptions in the line, but don't take excessive risks of obsolescence or unneeded inventory." Amendments to these directives are likely to be just as broad and vague.

Management needs a tool that will describe its policies in such a way that they can be precisely and uniformly interpreted by requisitioners. The advent of high speed computers makes it impossible to rely on individual decisions. Despite the ability of the computer to make a staggering number of exactly correct computations in seconds, the simplest intuitive decision is completely beyond its capabilities. Management decisions have to be made in the only terms the

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[1] Whitin, loc. cit., p. 5.

machine understands: exact instructions expressed in mathematical terms.

Scientific inventory control is this tool for better management control of inventory decisions. It requires the evaluation of the many individual factors which enter into decisions, and this is good, whether the business or distribution system be large or small, or whether the results of the decisions come from people or electronic computers. It encourages the combination of problems that are alike for blanket decisions and the separation of problems that are different for individual decisions. It encourages the application of the most effort and analysis to the items which are important, and of the least to those items which are not so important.[1]

Today's business magazines are devoting much space, and management seminars are devoting much time, to this "new approach" to inventory control. The facts are that a few far-sighted experts have been writing about inventory formulas for a long time, and several companies have been applying them for as long as twenty-five or thirty years. Yet for some reason, acceptance of the application of formulas is just beginning to come into its own in modern business. The advent of the data processing machine may be having an effect, but that is not the whole answer. Whatever the reason, the recognition of the potential value of expressing judgment through mathematics is

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[1] Welch, op. cit., p. 13ff.

gaining by leaps and bounds.[1]

To understand the principles of the analytic approach, one must have some idea of the basic functions of inventories. Fundamentally, inventories serve to uncouple successive operations in the process of making a product and getting it to the consumer. Inventories make it unnecessary to gear production directly to consumption or, alternatively, to force consumption to adapt to the necessities of production. The essential question is: At what point does the uncoupling function of inventory stop earning enough advantage to justify the investment required?[2]

Working without a complete analysis of the determining factors, there is a tendency to make or buy too much of the high cost items (creating unneeded inventory) and too little of the low cost items (creating too many orders and costly stockouts). The short procurement time items are bought or made too soon (again creating unneeded inventory) and the long procurement items too late (again creating stockouts). Better decisions result in lower inventory, few orders, and improved service.[3]

Quantification of Parameters--Working Stocks

We have been talking of the values of the analytical approach and quantification of inputs; what does this mean in terms of how much and when factors of inventory? Broadly

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[1] Ibid., p. 15. [2] Magee, loc. cit., p. 160.

[3] Welch, loc. cit., p. 14.

speaking, we are talking about one thing: optimization of costs. In the economist's approach, we recognize that funds are not unlimited to do all the things that we wish; therefore, we recognize the constraints put upon us by the limitation of our resources. To generalize even further, we are concerned with three cost factors influencing inventory decisions: the costs of obtaining inventories, the costs of carrying inventories, and the costs of not having inventories when needed, or what is called shortage or penalty costs. We seek to characterize the optimal policy for the dynamic inventory model in terms of the various cost factors combined with the uncertainty of demand.[1] It is essential to recognize, however, that in the application of the economist's approach, it is impossible to choose that policy which simultaneously maximizes gain and minimizes costs, because there is no such policy--maximum gain is infinitely large, and minimum cost is zero.[2]

Recognizing that the scientific decision approach is to ackowledge the different parameters, we find that there is a high degree of unanimity of what costs should be considered. Magee provides a comprehensive definition of the costs that directly influence inventory policy:[3]

Costs depending on the amount ordered include quantity discounts offered by vendors; set up costs in internal

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[1]Arrow, Karlin, and Scarf, loc. cit., p. 135.

[2]Hitch and McKean, loc. cit., p. 165.

[3]Magee, loc. cit., p. 163.

manufacturing operations and clerical costs of making out a purchase order; and, when capacity is pressed, the profit on production lost during downtime for setup. Shipping costs represent another factor to the extent that they influence the quantity of raw materials purchased and resulting raw materials stock levels, the size of intra-plant or plant-warehouse shipments, or the size and frequency of shipments to the customer.

Production costs, beyond setup or changeover costs, mentioned above, include the abnormal or non-routine costs of production whose size may be affected by the policies or control methods used. Overtime, shakedown, hiring, and training represent costs that have a direct bearing on inventory policy.

Costs of handling and storing inventory include expenses of handling products in and out of stock, storage costs, such as rent and heat, insurance and taxes, obsolescence and spoilage costs, and capital costs. Inventory obsolescence and spoilage costs may take several forms, including outright spoilage after a more or less fixed period; risk that a particular unit in stock or a particular product number will become technologically unsalable except at a discount or as spare parts, or go out of style, etc.

In a production environment another author[1] states that in repetitive manufacture, where the annual output is made up of long runs of identical pieces, a sufficient number of pieces

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[1] L.P. Alford and J.R. Bangs, Production Handbook (New York: Ronald Press Co., 1945), p. 99.

must be run in each batch to offset the cost of planning, ordering, tooling, moving, and making ready the work and the machine, but not so many as to incur avoidable carrying charges on idle finished parts. There is obviously a point at which these two influences will balance each other.

Unfortunately, however, nowhere in the accounting department is there found the cost of an order for even the simplest inventory; nor is there a figure for the cost of carrying an inventory. While there is agreement on the formulas, there is a variation in views on the determinations of the constants. This variation, though, does not appear to vary largely in the final result, even though different subsidiary inputs are used. In the holding cost estimate, for example, Alford and Bangs[1] state that inventory carrying charges for average warehouse stocks should be set at about 25% per annum. This is divided as follows:

Storage Facilities. . . .	.25%
Insurance	.25
Taxes	.50
Transportation.	.50
Handling and Distribution	2.50
Depreciation	5.00
Interest.	6.00
Obsolescence.	10.00
	25.00%

An important element in the determination of which rate to assign is whether the item is an active item or a desirable item. Depreciation, including deterioration, obsolescence, shrinkage and perverted or uneconomical use, and expense,

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[1] Ibid., p. 397.

including extra handling, accounting, in addition to those mentioned above, are higher for desirable items than for active items.

It is obvious that the cost of carrying inventory will vary greatly for different classes of material. Each company should make its own estimate based on its experience of handling and storage charges, and losses from depreciation, obsolescence, etc. To indicate that "ball park" figures are quite often satisfactory, Whitin states[1] that three companies replying to a questionnaire used holding rates of 20%, 18%, and 17%.

In the Navy, a number of studies has been made to determine the cost of holding stock at various supply activities. These studies have shown that, system-wide, the warehousing and other physical costs amount to less than 1% of the average inventory valuation. Even for items requiring special handling or a controlled environment, such as refrigerated storage space, these costs are only about 2% of the inventory value. However, there are two other elements of the holding costs which are roughly ten to 100 times as important as the physical holding costs. These are the obsolescence cost and the interest rate or time preference rate.[2]

Obsolescence cost is the portion of holding cost which reflects the fact that demand for the item may disappear or

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[1]Whitin, loc. cit., p. 220.

[2]Bureau of Supplies and Accounts, Introduction to Variable Stock Levels, p. 3-14.

fall off drastically. If this occurs, the item is generally disposed of at a fraction of its original value. This loss of of value at disposal time is a part of holding cost, since it would not have been incurred if the item were not held in stock. Since the obsolescence cost is obviously dependent upon the cost of the item which may become obsolete, it is usually expressed as a percentage or fraction of the unit cost, in the same manner as other portions of the holding cost. Obsolescence costs can be very high (over 100% per year for new technical repair parts on sophisticated weapons systems subject to engineering modifications), but probably range from 3% to 10% for general stores material.

The interest or time preference rate reflects the fact that money is scarce, or more specifically, that there are other immediate uses for money than investment in inventories. Even if there were no such thing as physical holding cost or obsolescence cost and no demand uncertainty, one would still not buy the total future expected demand for an inventory, because money is too valuable in other uses. A quantitative measure of this "value of money" is the interest rate, or as it is called in the Navy, time preference rate. If money is scarce or "tight" the effective interest rate is high; if money is plentiful, the interest rate is low. With the very tight budgets the military services face, the effective interest rate for inventory investment is in the neighborhood of 15%. Therefore, for each dollar invested in inventory, it is assumed that there is a charge of 15¢ per year which must be

added to the holding cost. It is obvious that this time preference rate cannot be precisely determined, but it has been fairly well estimated. For example, in applying scientific inventory control procedures to provisioning spare parts for components of the Polaris missile program, Admiral Raborn was asked how much money he would give up out of this year's budget if assured of a certain amount next year. His reply was equated to a preference rate of about 20%. Other estimates have been derived in a similar way, for example, considering the implicit balance between funds available for buying stock, and funds available for operations, or the procurement function. From this has been derived the 15% figure referred to.

Three elements of the holding cost have been discussed: storage costs, obsolescence costs, and interest costs. Since the last two are much larger than the first, and since they are roughly proportional to the unit cost, it is common to express the complete holding cost as a function of the unit cost. The Navy used a 20% annual holding cost in its initial implementation of these policies, which was centered around general stores material.[1]

This has been a rather rigorous exposition of the cost parameters of the working stock portion of inventories. It was done for the purpose of pointing up the many factors that must enter into the decisions to be made. In fact, most

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[1] A.J. Gradwohl, Technical Description of the BuSandA Stock Table Program, Report PRC-262 (Santa Monica, Calif.: Planning Research Corp., 1 August 1962), p. 25.

decisions in our business and personal lives involve weighing the divergent results of alternate decisions, and it is the primary point of this paper that these decisions represent alternative values or costs. This is implicit in all decisions that are made. And so it is with inventories. The decisions of how much and when of inventory usually will be the measurement or comparison of the relative costs of one decision as compared to another. In doing this, managers may make completely arbitrary decisions as to the willingness to tie up funds in inventories of certain types. Under such special and limiting conditions, many have felt that statistical approaches are not applicable, when, in fact, mathematics may be the best possible means for expressing these limitations, and the application of formulas may be the key to their management.

The Formula Approach to Working Stocks

Why formulas at all? Requisitioners in inventory control and purchasing have been making decisions from a background of experience for many years, and companies have prospered. But that is not good enough in tomorrow's business world. Take, for example, the many parameters to inventory decisions that have been examined above. Management has its choice between relying upon an individual's appraisal of these factors, or of making a management decision as to how they should be evaluated. Under the pressure of competition and speeded-up business, it is going to be necessary to hire more individuals to make more intuitive decisions or to adopt

machine methods in order to speed up the whole decision-making process.[1]

The application of a formula to the determination of size of working stocks is based on the very simple concept of minimizing total annual costs of carrying an inventory and the buying of that inventory. Figure 6 depicts the relationship of the two factors. As the size of inventories increases, the total annual costs of carrying those inventories increases in direct proportion. On the other hand, as the amount of inventory increases, the frequency with which procurements are made decreases, and therefore the total annual procurement costs decrease. Mathematically this can be expressed as:

> Total annual costs = average working stocks x holding cost + number of annual procurements x reorder cost.

The point was previously made that average working stocks are one-half the reorder quantity, which was denoted as Q. Therefore, $\frac{1}{2}Q$ is substituted in the formula. Holding costs are expressed as a percentage, i; unit cost as u; and reorder cost as C. The number of annual procurements is equal to the total annual demand dividend by the reorder quantity, so the number of procurements annually is expressed as Y/Q. The formula then becomes: $TAC = Q/2 \times ui + Y/Q \times C$. This solves into the classic "lot size" formula:[2]

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[1] c.f., Welch, loc. cit., p. 15ff.

[2] A.J. Clark, H.W. Karr, and J.R. VanderVeer, Mathematical Description of Inventory Control Calculator Models, Report PRC-100 (Santa Monica, Calif.: Planning Research Corp., 30 March 1959), p. 10.

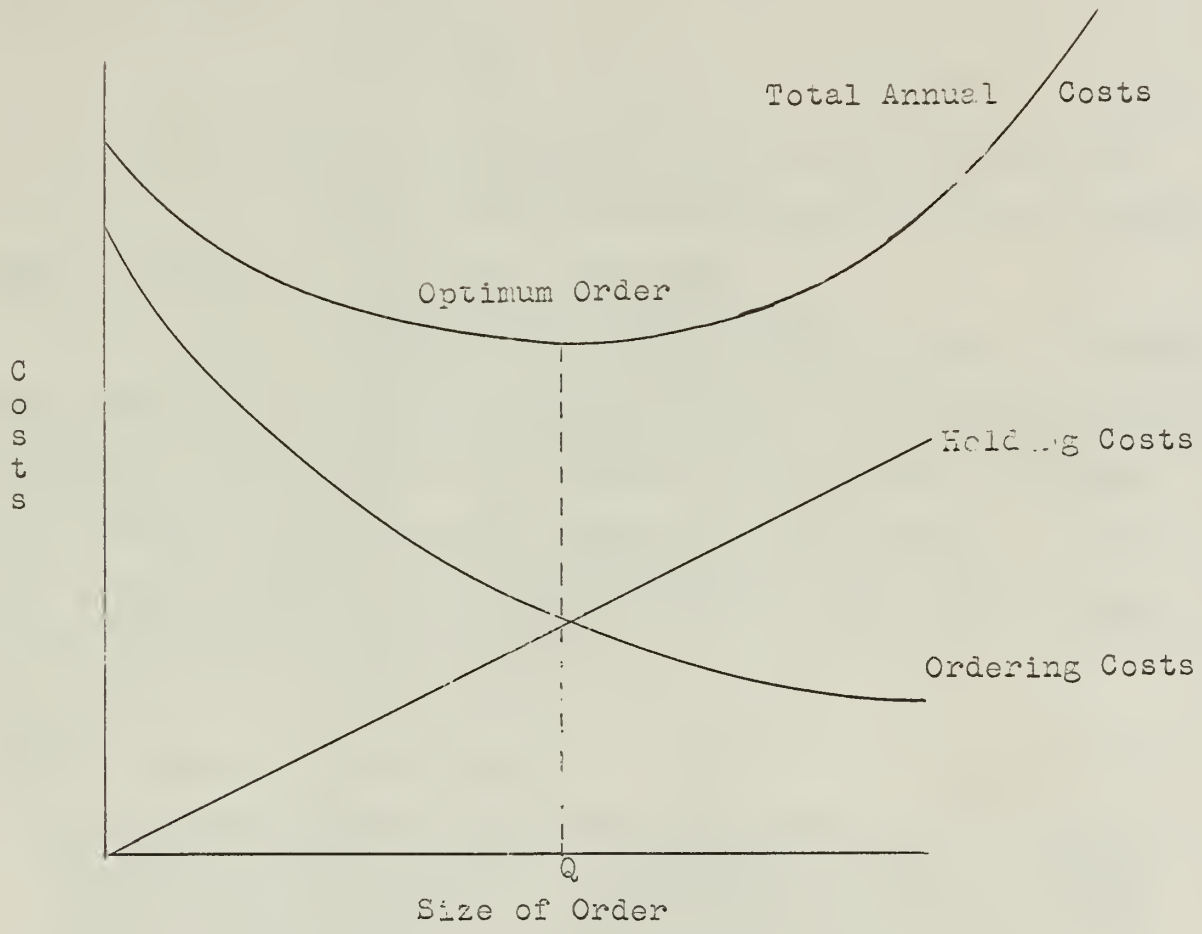

Fig. 6.--Graphic Presentation of Combined Ordering and Inventory Holding Costs

$$Q = \sqrt{\frac{2 Y G}{ui}}$$

Since the procurement costs, holding cost, and quantity 2 are all constants, they can be broken out as a constant ratio, k, and the formula becomes:

$$Q = k \sqrt{\frac{Y}{u}}$$

The principal conclusions to be drawn from this are:[1]

1. Order quantities vary directly with the square root of demand, and inversely with cost.

2. It is only the ratio of reorder cost to holding cost which affects optimum operating level for all items in the inventory, and as this ratio increases, the reorder frequency will decrease and the average inventory will increase; or as this ratio decreases, the reorder frequency will increase and the investment will decrease.

Reorder Point and Safety Stocks

> Another important element in the mechanism of the inventory process is the lag in delivery of the commodity after an order is placed or a decision is made to produce. If demand is assumed to be known with certainty this lag is of no consequence; all that is required is that the orders be placed correspondingly earlier. In the case of uncertain demand, however, the assumptions about delivery are important, since the information about the amount needed for ordering changes with time. The existence of lags in delivery is an essential element of inventory holding in so far as it serves to protect against uncertainty, for if deliveries could be made instantaneously without extra cost, the firm could place

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[1] Bureau of Supplies and Accounts, Introduction to Variable Stock Levels, p. 3-9.

its orders after knowing what the demand is rather than before and thus avoid all possibility of penalty costs.[1]

This succinctly states the purpose of reorder points, and introduces a new parameter. As previously indicated, safety stocks are established to reduce the probability of stockout during leadtime to something less than 50%. This implies that there is a cost involved with being in an out-of-stock position when there is a requirement for material, whether the cost is explicitly stated or not.

Quantification of Parameters--Reorder Point

Quantification of factors in the determination of reorder points revolves around two things: shortage costs and probability of demand.

It is easy enough to understand the principle that setting a safety stock implies some kind of management decision or judgment with respect to the maximum sales level to be allowed for, or the cost of service failure. But here is the "rub": service failure cost, though real, is far from explicit. It rarely, if ever, appears on the accounting records of the company, except as it is hidden in extra sales or manufacturing costs, and it is characteristically hard to define. What is new in inventory control is not an accounting technique for measuring service cost, but a method of self-examination by management of the intuitive assumptions it is making.[2] The

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[1]Arrow, Karlin, and Scarf, loc. cit., p. 24.

[2]Magee, loc. cit., p. 172.

concept of depletion costs or shortage costs has been considered by other authors, also.[1] We should, therefore, examine this concept to see what this implicit value is in the setting of safety stocks.

In a business environment, it would certainly include customer dissatisfaction, loss of profits, etc., as well as the costs of special orders and manufacturing. In the military this is referred to as expediting costs, which include special communications, transportation, and handling. These are certainly understandable, and even somewhat measurable in a broad sense. A distinction must be made, however. Many authors, in discussing safety factors, are beguiled by the mathematical convenience of assuming that there is a known cost of being in backorder and derive elaborate models for selecting a safety factor that will balance the cost of carrying inventory against the expected cost of being in backorder. Frequently this assumption is merely a confusion between the value of avoiding a backorder and the cost of having a backorder, which may not be the same at all.[2] This brings up a special consideration applicable to military inventories: the shortage penalty.

Markowitz discusses the shortage penalty and a methodology for approximating it in various environments.[3] He

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[1] Whitin, loc. cit., p. 60.

[2] R.G. Brown, Statistical Forecasting for Inventory Control (New York: McGraw-Hill Book Co., 1959), p. 119.

[3] H.M. Markowitz, Shortage Penalties in Missile Spare Parts Logistics, Report RM 58 TMP-27 (Santa Barbara, Calif.: General Electric Co., 31 December 1958).

points out that the shortage penalty plays a significant role in missile spare parts logistics. In fact, the existence of shortage penalties is the sole reason for stocking spare parts. If there were no shortage penalties, i.e., if the missile squadron went unpenalized when part shortages occurred, there would be no purpose in spending money on spare parts, and the spare parts logistics function would be non-existent. Without this function the missile system would be off the air a great deal of the time, thus creating an untenable situation. Nearly everyone concerned with supply systems readily admits the existence of shortage penalties, but like so many of the other parameters that enter into the inventory decision, they are not known exactly, and therefore, there is a tendency to avoid considering them. In this case, people have avoided stating a dollar figure because it is dependent on so many factors that quantifying it is nearly impossible. But the concept is not completely vague--for any inventory policy there is associated a cost and a resulting effectiveness.

This introduces another concept that is the subject of much research today, particularly in the Navy. The term used is "military essentiality" or "military worth." Simply stated, this is nothing more than a realization that all items in an inventory do not have the same importance regarding the effectiveness of the operating forces. For example, paper and pencils for a public information office are certainly not as important as a spare part for a missile system. This is just

common sense, but it is surprising how often this simple concept is ignored. The very fact that effectiveness of the Navy Supply System is measured in terms of items available versus total demands at each supply installation of the Navy is one indication.

The George Washington University Logistics Research Project, under contract to the Bureau of Supplies and Accounts, Navy Department, has been exploring this area for some years, and is the prime source of the concept within the Navy.

The concept is based upon the effect of the failure of a particular equipment to the mission of the ship or aircraft; the effect of the failure of a component within the equipment to the operation of the equipment; and the effect of the failure of a part within the component to the operation of the component. As a mitigating factor, alternative sources or methods of compensating for the failure of the part, component, or equipment are considered. For example, if more than one equipment is installed, the equipments are said to be redundant if they serve the same purpose--the failure of one would not prevent accomplishment of the mission. Similarly, if a failed part, component, or equipment can be jury-rigged, or cannibalized, or other alternative solution arrived at without a replacement part, the seriousness of the failure is mitigated. The essence of this program is to arrive at a hierarchy of importance of individual items to the mission of the ships of the fleet.

In the first GWU report, in 1958,[1] there was a total of twenty rankings based upon four military worth considerations of equipments and five maintenance potentials. The most recent study, one now being used in the Polaris program,[2] indicates a possible 2,916 classes, but through aggregation this has been reduced to 116, of which only fifty-eight are applicable at the shipboard level. The 116 is based on twenty-nine military worth considerations of equipments and components times four different part considerations.

This concept has found Navy-wide adoption. The Chief of Naval Operations through his Instruction 4423.1A, of 23 November 1962, has required its use for all ships, aircraft, and their supporting logistic elements. This is one way for the military to get "a handle" on the different repair parts and materials by a logical, structural, decisive process. Referring back to the discussion of the economist's approach in Washington, Hitch also recognizes the responsibility of the military services to determine the military worth of marginal operations.[3]

Shortage cost, as we use it in the Navy, is a meld of military essentiality and the shortage penalty. A penalty would be assumed for a particular activity, and the relative

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[1]U.S., Department of the Navy, Bureau of Supplies and Accounts, Military Worth (The George Washington University Logistics Research Project, Washington, D.C., 24 April 1958).

[2]U.S., Department of the Navy, Bureau of Supplies and Accounts, Polaris--The Optimum COSAL Program (The GWU Logistics Research Project, Washington, D.C., June, 1961).

[3]Hitch and McKean, loc. cit., p. 222.

essentiality of a part would factor the penalty from 0 to 1. Once again, preciseness in the stating of either of these concepts is not necessary to be beneficial. It is the recognition of the relative importance of different spare parts, together with the potential cost of stockout that is important.

It has been shown that there is a risk of potential stockout during leadtime, and that this stockout has a cost implied. Conversely, in the holding of safety stocks to minimize the risk of stockout, there are costs associated, which have been described under the holding costs aspects of working stocks. It is obvious that the higher the implied shortage costs, the higher will be the safety stocks; and the higher the holding costs, the lower will be the safety stocks. Safety stocks, then, are a function of the ratio of holding costs to shortage costs.

Leadtime is important to the setting of safety stocks, for the purpose of safety stocks is to reduce probability of stockouts during leadtime. Fortunately it is easier to quantify than some of the other parameters. There are two important factors to consider in estimating the leadtime for an item.[1] The first is that the total leadtime must be considered, and the other is that the expected leadtime should be based on past procurements from a source similar to that from which additional material will be received.

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[1] Bureau of Supplies and Accounts, An Introduction to Variable Stock Levels, p. 4-44.

The leadtime for an item begins when it is decided that action must be taken to order, purchase, requisition, manufacture, or repair an item, and ends when the material is received. The time in weeks from the action dates to the receipt dates on various stock records is generally an accurate statement of past total leadtimes.

The total leadtime for an item depends on the type of action taken to replenish the item. Thus, the time to replenish an item by repairing existing stock may be less than the time to replenish by requisition from a supporting supply activity. In estimating the total leadtime for an anticipated replenishment, it is necessary to determine the probable type of replenishment and then analyze the leadtimes for past replenishments of the same type. Generally, averages can be calculated for different items, and it is not necessary to make a calculation for each item with each replenishment.

By far the most important factor affecting the reorder point and safety stocks, is demand. The preponderance of low demand, high variability items in the military inventory has been discussed, and indicates the problem of attempting to anticipate requirements.

The very idea of demand during leadtime, discussed as the basis for safety stocks, denotes the necessity for arriving at some idea of average demands, but how much history should be used to arrive at this average? Generally, the longer the historical period the more that fluctuations will be smoothed out, but it must be noted that too much history may be as bad

as not enough, for current effects on the particular item, such as changing equipment populations, may be negated. It has been determined through study that Navy supply predictions should use a two-year base.

In a period of phasing new equipments into the service, or of phasing old equipments out, we experience trends in demand, which the simple average does not adequately recognize. There are two methods of compensating for trend: the "Least Squares" prediction and a weighted average of demand. The first method fits a trend line through a group of observed data to project a prediction into the future along that trend line. The objection to this approach is that it is complicated, computationally, although it has been used with some degree of success at the Electronics Supply Office of the Navy. The weighted average method has been used for some years at the Naval Ordnance Supply Office, and is a method of assigning weights to the periods of demand used, with the most recent period receiving the most weight.

Recognizing that extreme fluctuations in random demand exist, particularly for low average demand items, in order to utilize trend compensating methods of demand prediction guidelines must be established to differentiate between actual trend and random demand. This problem is similar to that of quality control on a production line. As stated earlier, servomechanism techniques are being applied to control this phenomenon.

The use of averages introduces the crux of the discussion on demand, and that is probability theory.

For every average of demand over leadtime, it is possible to construct a probability distribution table based on observed demands--empirical data. For each one of these distribution tables, a cumulative distribution can be constructed based on the probability of z or more demands occurring. Thus there would be a 1.00 probability of zero or more demands, something less for one or more, etc. The risk of stockout that has been referred to would be the sum of the probabilities in the "tail" of the cumulative distribution higher than any particular value of z selected, wherein z would be the reorder point for that average.

This is impractical when considering any group of items, so the use of mathematical probability distributions is utilized. This, of course, is a set of standard tables which accomplish the same purpose as constructed tables, but in effect, smooth out the "bumps" and "valleys" in actual observed occurrences. By the use of these tables, a supply manager need only ascertain the degree of risk he is willing to take on being out of stock on each item; go to the appropriate table for the average under consideration; and select the figure associated with the probability of that risk. That quantity is then his reorder point in the same manner as it would be with empirical tables. Figures 7 and 8 illustrate this idea.

Statistical studies of military inventories have

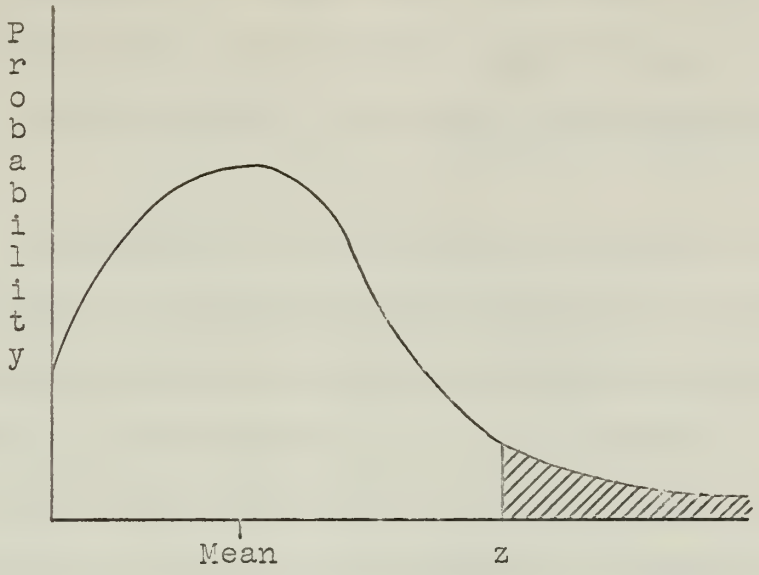

Fig. 7.--Hypothetical Probability Distribution

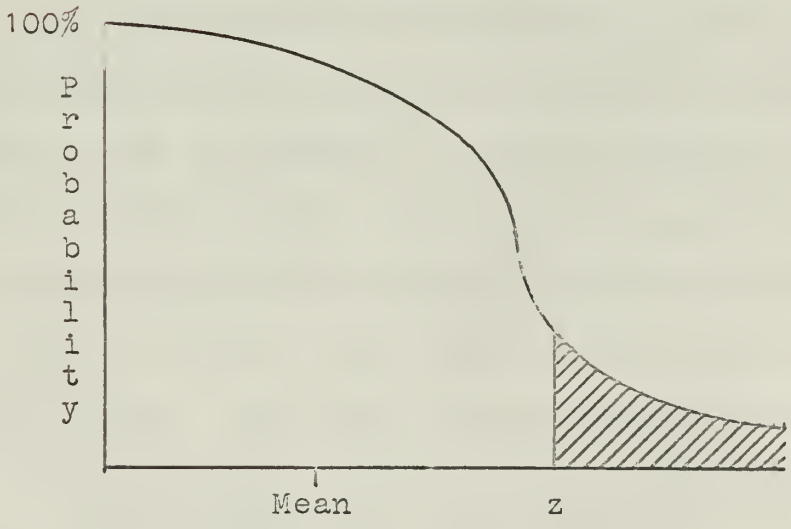

Fig. 8.--Hypothetical Cumulative Probability Distribution

applied the "Chi-square" test of best fit, and have ascertained that three standard probability distributions best approximate actual occurrences. These are: the normal distribution for large demand items; the Poisson distribution for medium demand items; and the negative binomial distribution for low demand items.[1]

The question to be answered, however, is where in the tail of these theoretical distributions do we accept the risk? Some people advocate the use of a standard degree of risk for all items in an inventory by use of a factor of so many standard deviations from the mean,[2] but this is not wholly satisfactory, because of the military essentiality parameter.

The Formula Approach to Reorder Points and Safety Stocks

The point has been made that safety stocks are a function of the ratio of holding costs to shortage costs. They are also a function of the frequency of orders in a year, for the more often that an item is ordered, the more often it is exposed to the probability of stockout during leadtime. The formula approach, then, becomes one of minimizing total annual costs of holding costs and shortage costs, in the same manner that holding cost and procurement costs were optimized for working stocks. The Navy's prime contractor in the area of

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[1] U.S., Department of the Navy, Bureau of Supplies and Accounts, Provisioning Subcommittee Report, (Advance Copy) (Washington, D.C., 18 May 1962).

[2] Whitin, loc. cit., p. 48.

inventory control research has utilized dynamic programming techniques to arrive at what in essence is a very simple formula for ascertaining the maximum degree of risk of stockouts during leadtime we should be willing to take:[1]

$$\text{Probability (Actual demand during leadtime exceeds reorder point)} = \frac{(\text{Holding Cost})(\text{Reorder Quantity})}{(\text{Shortage Cost})(\text{Annual Demand})}$$

It can be seen that the formula recognizes the ratio of holding cost and shortage cost, as well as the frequency of reorder. The actual solving of this expression was expressed as an optimization of the combined reorder costs, holding costs, and shortage costs. In this paper they have been separated for simplicity of presentation.

Implications for Management

Utilization of scientific inventory management techniques gives management a tool for controlling the effectiveness of its inventory policies which it never had before. As in any form of scientific management, the structuring of decisions requires management to analyze the interrelationships of parameters that enter into decisions. This analysis quickly indicates to the manager which factors are relatively more important than others, and allows him to concentrate his attention and efforts where they will produce the most benefit.

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[1]Clark, Karr, and VanderVeer, loc. cit., p. 11.

Attempts to introduce the concept of scientific inventory management have met with much resistance from operating personnel. This resistance is engendered partly by a lack of full comprehension of the concepts involved, but probably more from the difficulties involved in quantifying parameters. The lack of ability to be precise in assigning values to such factors as the cost to hold, causes many to react against the validity of the entire concept. It is encumbent upon managerial personnel who desire to utilize concepts such as this to: first, ensure that their subordinates are aware of what the concept is and what it means. Secondly, they must demonstrate that errors in parameter values do not engender the same degree of error in optimum policies, and of more importance, that the estimation of parameters individually for manipulation by a logical mathematical approach gives more consistent decisions which are in themselves much better than the intuitive approach to inventory control. The very fact that the order quantity is a result of a square root function, and the reorder point is the result of a probability distribution function indicates that the results of decisions are not linear with the variability of the parameters.

One of the major benefits to management is that they now have the ability to project the results of a decision, and to make decisions on the basis of those projections or simulations. The Monte Carlo simulation technique uses tables

of random numbers as substitutes for actual demand; numbers are taken from the table, and through iterative procedures in a computer are applied to probability distributions to arrive at random demands. This figure is then applied against an inventory model set up on the basis of a management decision and the issue is simulated, along with reorders, when necessary, the arrival of material, and stockouts. In a few minutes' time the action of an inventory for a period of weeks, months, or even years can be simulated.

Through the use of models and by varying parameter values, management is able to make decisions with a better knowledge of the consequences of those decisions. In inventory management the manager is concerned with what level of effectiveness or customer service he can attain without undue increase in the costs of managing the inventory. Figure 9 is an example of how this can be accomplished. By varying parameters in a simulation process, several curves such as shown can be derived, and the most economical one chosen, and those parameters assigned to decisions. Within the Navy this device has been used with some success.[1] The most important thing to recognize is that it gives the manager the ability to set a policy with a much higher degree of assurance that this

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[1] R.G. McIntosh and A.J. Gradwohl, Report on Phase A, Polaris Fire Control System Logistics Management Study, Technical Military Planning Operation Report R50TMP-6 (Santa Barbara, Calif.: General Electric Co., 30 January 1959), p. 18. R.G. McIntosh, Improvement of Local Supply Decision Rules at NSC, Report PRC-132 (Santa Monica, Calif.: Planning Research Corp., 1 October 1959), p. 17.

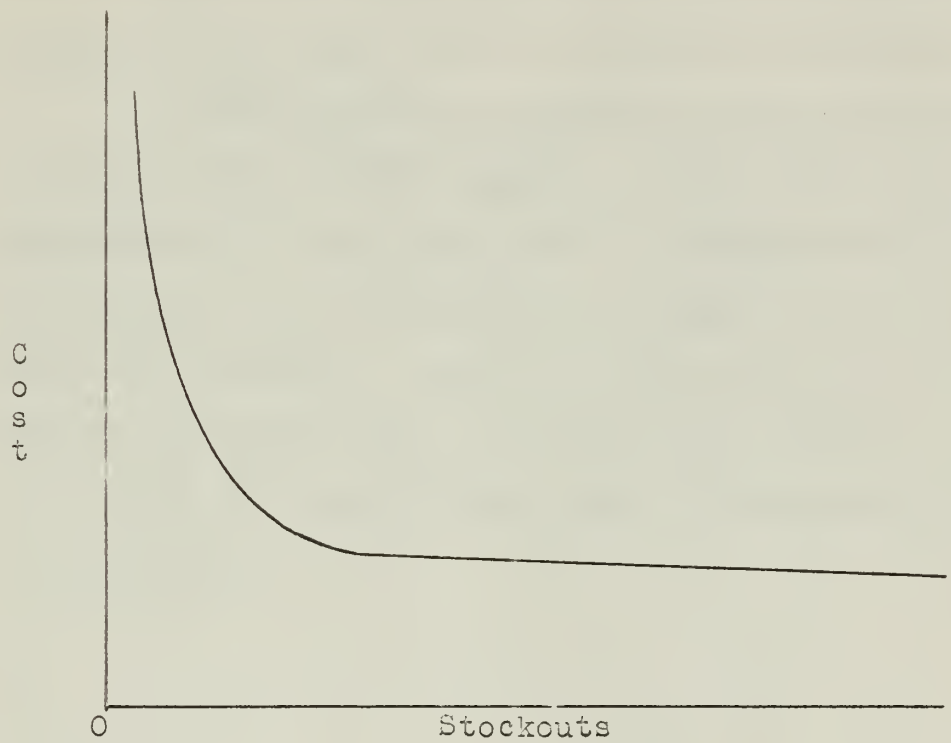

Fig. 9.--Relationship of Cost to Effectiveness

policy will be consistently followed, and it gives him more flexibility. If his funds are cut, for example, he can increase the funding constraint or time preference rate to reduce the amount of inventory that will be held and at the same time realize that he is increasing the risk of stockout. The point is that he will know what the results of a decision will be.

In introducing new programs, most of them fail when something unanticipated happens. Inventories may build up unexpectedly, or the order rate may increase more than anticipated, and soon everyone is happy to return to the intuitive approach.[1] One way to avoid this is to analyze present procedures and to introduce new methods in a way that will assure some improvement without attempting the optimum at the beginning.

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[1]Welch, loc. cit., p. 17.

CHAPTER V

THE CONCEPT APPLIED TO THE AFLOAT INVENTORY

Operational Readiness[1]

The only reason in being of the entire military logistics complex is to ensure the combat or operational readiness of the combat forces. In Chapter II the point was made that the purpose of inventories is to buy time, and that in a military inventory the time that is being bought is operational time of weapon systems. Yet in the past, this point has been only dimly conceived, and even then not too much importance has been given to it. It has only been recently that decisions regarding inventory control have begun to be structured into a logical arrangement, whereby the end purpose is explicitly considered.

The concept of operational readiness is essential to an understanding of the reason for inventories aboard Navy ships. The Navy is built around a number of different weapon elements, i.e., aircraft carriers, destroyers, submarines, etc.,

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[1]The constructs of this section were, for the most part, derived from an article, "Military Essentiality," by Commander H.F. Mills, Supply Corps, U.S. Navy, in Monthly Newsletter--Magazine of the Navy Supply Corps, Vol. XXVI, No. 3 (March, 1963). It is the opinion of the writer that Commander Mills has one of the finest conceptual minds of anyone in the Navy regarding the meaning of supply support. For this reason the liberty has been taken of freely extracting ideas and concepts from his work.

each with a mission falling within the mission of the Navy as a whole. However, one factor peculiar to the Navy as differentiated from the other services, is that each ship is capable of performing more than one mission, particularly in the destroyer force, where the missions assigned may be anti-aircraft, anti-submarine, or shore bombardment in nature. At any time the operational readiness of a ship is its capability of performing a particular mission that has been designed into the ship, and the Commanding Officer in reporting his ship ready for sea must consider the interrelationship of the various missions of which his ship is capable, as well as the primary mission(s) assigned to him at the moment.

The ability of a ship to carry out a particular mission depends upon its ability to perform a number of major functions, each of which can be thought of as carried out by a system. Each of these systems in turn is dependent upon the performance of sub-systems, which together comprise the parent system. Commander, Cruiser-Destroyer Force, United States Atlantic Fleet and his staff have suggested that the destroyer as a weapon system is comprised of the following systems and sub-systems:

1.0 Mobility

- 1.a Propulsion
- 1.b Hull
- 1.c Auxiliary
- 1.d Navigation

2.0 Target Detection and Location

2.a Air Targets
2.b Surface Targets
2.c Sub-surface Targets

3.0 Weapon Delivery

3.a Air Targets
3.b Surface/Shore Targets
3.c Sub-surface Targets

4.0 Personnel Support

4.a Health
4.b Safety

5.0 Communications

Using a guided missile frigate as an example, there is a primary mission of anti-aircraft defense of a task force; however, within the mission capability of the frigate is an anti-submarine capability, as well as surface or shore bombardment of a limited scope. Within the weapon delivery system of the anti-aircraft defense mission are the sub-systems of a guided missile system and a gunfire system. Within the guided missile system are sub-sub-systems of missile launching system, fire control system, and the missile itself. Within the fire control system, the most complicated, perhaps, is the missile radar, which tracks the target and provides electronic guidance to guide the missile to its target; several computers to correlate the action of the radar with changes in target course, speed, etc.; and weapons control equipment which controls the operations of the entire guided missile system, from target acquisition through missile firing

to target destruction.

This structuring of the weapon system can be continued down through the equipments comprising the sub-sub-systems to the components comprising the equipments and the parts comprising the components, so that eventually there is a relationship between mission performance and parts performance. Figure 10 indicates the hierarchial relationships of the mobility system. In considering the ability of the ship to perform its mission it is important to recognize that the operational readiness is a factor of the systems acting in combination, and the performance of the sub-systems down to the components is also one of interrelationship of things acting in combination.

Once the hierarchial relationships of the equipments within a ship are recognized, it then becomes necessary to determine what the levels of performance are for each of the systems within the ship-system. There can be many levels of performance; therefore, judgment must be used to reduce the alternatives for selection to a relatively few significant ones. For example, in the propulsion sub-system of the mobility system, there is an infinite number of possibilities, ranging from 0 knots to the maximum speed designed in the ship. However, there is little advantage to be gained from differentiating between minute changes in speed capability. COMCRUDESLANT has divided the alternatives into three groups:

1. Capable of full speed with split plant operation.

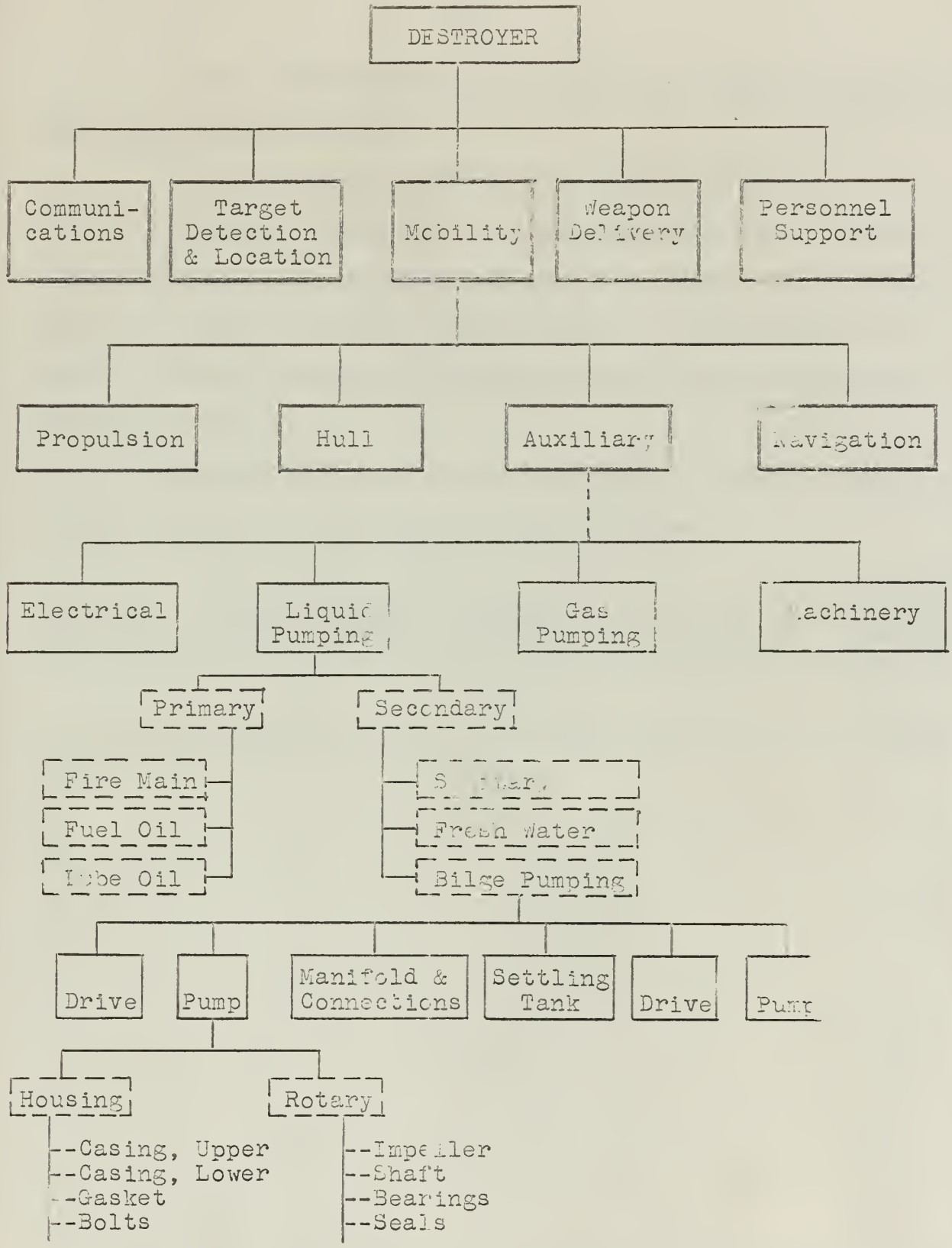

Figure 10.--Relationship of mission performance to part performance.

2. Any conditions less than the above but greater than those described below.

3. Capable of less than standard speed.

This is an example of the type of judgment that must be made in determining the operational readiness of a ship. An extension into the field of missilry might require a consideration of rate of fire of missiles or seconds of degrees in computer or radar oscillation.

When the variables for each system are determined, it is then possible to arrange a matrix as follows:

Levels of Performance	Mobility	Target Detection and Location	Weapon Delivery	Communication	Personnel Support
	A	B	C	D	E
	1		1		
		1		1	
	2		2		
		2		2	1
	3		3		
		3		3	2
	4		4		2

This chart rather crudely depicts the different states that this ship theoretically could be in, ranging from the best state, when all equipments are operating at designed performance, of A1, B1, C1, D1, E1 to the worst of A4, B3, C4, D3, E2, when all equipments are down. There is a total combination of 288 combinations of states of readiness (4 x 3 x 4 x 3 x 2). These can be put in a ranking order to describe differing degrees of readiness, and as such would constitute an index of readiness. However, to put all ships on the same basis the rank order should be transcribed to a percentage basis so that 100% readiness would be meaningful to all concerned. Commander Mills suggests that the relationship is not linear, but rather exponential, and in fact, exponential scaling of the hierarchy was used in construction of the allowance list for the Polaris program, as will be described later.

An important factor to note is that the level of performance of the systems, the sub-systems, etc., down to the parts can be done by those in the command structure best fitted to determine their importance. The Commanding Officer, for example, would describe levels of performance of the systems, the department heads of the sub-systems, division officers of the sub-sub-systems, down to the petty officer responsible for maintaining each component describing the levels of importance of each part to component.

Another important factor is that the performance of each level of the hierarchy is dependent upon or mitigated by the importance of the elements of the level just below it, and

that there is a cumulative effect. A part that was 100% essential to its component, which in turn was 100% essential to its equipment, on up to the system, would have as much essentiality to the operational readiness of the ship as the weapon system itself.

Recognizing the interrelationships of the various systems, etc., to the operational readiness of the ship, the question arises as to what this means in terms of supply management. The answer is in terms of failures of different parts in different components of equipments.[1] As the equipments are operated, parts fail, they are repaired, operated some more, and other parts or the same ones fail again. Sometimes the parts that fail are in stock aboard ship and sometimes they are not.

This cyclical process in the life of a component or equipment can be conceptualized by breaking it into three main time periods. There is the mean (average) time between failures, mean repair time, and mean time waiting for parts. The sum of these is the total operational time of the equipment; the ratio of mean time between failures to the total operational time is the effectiveness, "up" time, or reliability of the equipment. It should be noted that the design engineer designs the equipment to be as reliable as possible, i.e., he

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[1]U.S., Department of the Navy, Bureau of Supplies and Accounts, Assistant Chief for Research and Development, "Military Essentiality Coding," OW Notes (Washington, D.C., 22 October 1962), p. 2-5.

tries to extend the mean time between failures to as long a period as possible. On the other hand, the mean repair time is a function of how well the equipment can be maintained--how easy is it to "trouble-shoot" the equipment, how difficult is it to replace failed parts, etc.? To a certain extent this, too, is a design feature of the equipment, and should be considered by the engineer concurrently with reliability. Another engineering consideration which reduces both the mean repair time and the mean time waiting for parts is redundancy of equipments, which is to say, that more than one equipment performing the same function is designed into the ship to reduce the sum of mean repair time and mean time waiting for parts to zero, as far as operational readiness of the ship is concerned. This is done quote often in the case of highly essential sub-systems, and provides some latitude in spare parts stocking.

To synthesize the concept of the effect of performance level of the systems on the operational readiness of the ship with the concept of the cycle of component failure, it can be seen that as parts fail, the operational readiness of the ship is reduced by varying degrees, depending upon the importance of the part, and the time it takes to repair the equipment; the repair time is a function both of actual repair time and time required to obtain a spare part. This, then, is the crux of this thesis: funds available for stocking spare parts on board ship should be spent on those parts which will reduce time waiting for parts in the areas where operational readiness will

be increased to the maximum extent. This is the time we buy with shipboard inventories.

Military Essentiality Coding

One of the greatest strides forward that has been taken in applying structured decision-making concepts to afloat inventory management has been the implementation of the Military Essentiality Coding Program, which was developed through The George Washington University Logistics Research Project, and was briefly described in the previous chapter. The purpose of Military Essentiality Coding (MEC) is to establish a basis whereby personnel of ships and aircraft can formally evaluate the relative military importance of on-board equipments. The military importance assigned to an equipment will be determined by relating the function of the equipment to the accomplishment of assigned missions.[1] The immediate purpose is to relate repair part support to the ability of a ship or aircraft to perform its mission(s). In other words, MEC is the application of the concept of operational readiness as described in the preceding section.

The original allowance list study on MEC was commenced in 1957, and applied to submarines, the USS Tiru, a World War II fleet type, in particular. The purpose of this study was to develop techniques for making determinations regarding the

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[1]U.S., Department of the Navy, Office of the Chief of Naval Operations, OPNAV Instruction 4423.1A (Washington, D.C., 23 November 1962), p. 1.

range and depth of items to be included on shipboard allowance lists. Resulting from this study were technical papers explaining the results of intensive research in two areas: the development of a technique for determining the military essentiality of repair parts, and allowance list models. These technical papers were reviewed by the Special Projects Office in April, 1960. The Special Projects Office was interested in furthering the results of this early research effort for application to the Polaris submarine allowance list program. The results of this extension of the research program are described here, for the program developed is now being applied Navy-wide.[1]

One of the major problems in the development of optimum military inventory control systems has been the need of a measure of the relative importance of supplying one item instead of another. It had been generally recognized that some items were more important than others, but no way of objectively measuring and comparing the military essentiality of each item had been explicitly used in inventory control computations.

The research study was aimed at developing a technique for making military essentiality evaluations. This study, the most comprehensive ever initiated in the problem area, obtained military essentiality data on some 3,000 equipments and components and 51,000 repair part applications for the USS George Washington (SSBN-598). The military essentiality study

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[1] c.f., Bureau of Supplies and Accounts, Polaris--The Optimum COSAL.

included the active participation of personnel of the Bureau of Ships, Special Projects Office, Polaris contractors, officer personnel of Submarine Squadron 14, and the USS George Washington and USS Patrick Henry.

The immediate purpose of the study was to develop a military essentiality measure for use in allowance list preparation. The goal, initially, was to improve the Navy's capability for providing allowance lists maximizing the endurance of ships in consideration of budget and space constraints. It is important to note, however, that MEC in itself does not provide the data required. It is just one of the input parameters to provide the solution; however, for the first time it is being explicitly considered in the decisions that must be made in stocking a shipboard inventory.

The military worth of a repair part is based on a consideration of part-to-component-to-equipment-to-mission relationships. Repair part failures are examined in a series relationship--that is to say that the failure of a given repair part is not looked upon in isolation, but rather is dependent upon its application to a specific component, to a specific equipment, and to a specific ship's mission. In other words, it is the synthesis of operational readiness and material failure discussed in the preceding section.

Initiation of the military essentiality study was dependent upon obtaining a complete and accurate list of the installed equipments and components of the USS George Washington.

These were subjected to evaluation by three independent participants: the conctractors, technical bureau personnel, and fleet personnel. The purpose of obtaining multiple answers was, first, to determine if there was a particular bias from any one of the participants and, second, to obtain a measure of consistency.

The questionnaire for equipments and components included a statement of a typical patrol for a Polaris submarine. The most significant aspect of the statement was the requirement that the submarine stay on station independent of supply support for the full period of the patrol, and that in effect, the submarine would have to endure the loss of the function being performed by that failed component for the full length of the patrol. The mission requirement of independent operation for the full length of a patrol provides a measure of the seriousness of the failures being evaluated.

The format of the questionnaires for evaluation of equipments and for components was similar. The essential difference was that the one for equipments was concerned with the effects of failures of the mission of the ship, and the one for components was concerned with the effects of failures on the parent equipment.

The questionnaires were divided into three sections. The first has to do with mission effect. In this case the participant assumes the simultaneous failure of the sum total of equipments installed to accomplish a particular function.

For example, if three units of a particular motor are installed the assumption is that all three have failed simultaneously. The questionnaire requires the participant to render a decision on the effect that this simultaneous failure will have on the mission capability of the ship. Three choices are available; they range from failures which necessitate the immediate termination of the patrol action, to failures which have a negligible effect. The possible situations are indicated by numeric codes 2, 1, or 0, respectively. The participant determines which situation applies for each equipment/component in the study and checks the code number applicable to his decision.

A code 2 decision indicates a failure, the seriousness of which would cause the ship to break off the patrol and immediately return to port for repairs. A code 1 decision indicates a failure which would introduce a calculated risk into the accomplishment of the mission; the risk would be restrictive in terms of the operational capability of the ship. However, the ship would be able to stay on station. A code 0 decision indicates a failure which would have minimal effect on the accomplishment of the assigned mission.

The second question has to do with redundancy, which is the availability of duplicate installations of the same equipment and component, which, assuming the failure of the prime unit, can permit continued performance of the function of the prime unit. As in the previous question, three choices, similarly coded, are available to the participant. A code 2

decision indicates that there is no redundancy, i.e., there is only one unit installed, or if multiple units are installed, the failure of only the prime unit would be as serious as if all units failed simultaneously. A code 1 decision indicates that if the prime unit failed, the surviving units permit continued operation, but with some loss of effectiveness. A code 0 decision reflects the case where the surviving units permit continued operation with no loss in effectiveness.

The third question relates to the availability of alternatives or emergency methods to continue operations in the event of the failure of the prime unit. An example might be the case of an emergency power generator which is installed for emergency purposes, as the name implies. Jury-rigging of substitute operational capability is another case. The choices and coding for decisions are the same as in the case of redundancy of duplicate equipments.

In the case of the part questionnaires, only one answer--from technicians at the inventory control points--was obtained. Part essentiality is determined by technical judgment in two areas. The first is whether or not the part is installable by ships force under routine operating conditions with the tools and talent available. The second area of judgment is the effect of the failure on the parent component, and then only whether the effect is of major degradation of operation or minor degradation. These judgments are reported by four codes (1 through 4). 1 and 3 indicate installability by ships force. 1 and 2 indicate major effect, while 3 and 4

are minor. It can be seen that this decision brings together the reliability and maintenance policies ostensibly considered by the design engineer when first designing the equipments.

The MECs resulting from the study were ranked in order of importance. It can be seen that the number of classes was rather large. There were a total of twenty-seven equipment classes (three decisions with three choices each; 3^3) and twenty-seven component classes, or 729 total equipment/component combinations. Multiplied by the four part classifications, this made a total of 2,916 total possible ranks. This was obviously unworkable. The small differences are comparable to the difference between minute changes in speed capability used as an example in the discussion of operational readiness and levels of performance. It was, therefore, necessary to combine classes. The result was twenty-nine equipment/component classes times four part classes for a total of 116 MECs; however, since only two part classes were applicable to shipboard maintenance capabilities, the number of MECs considered for shipboard inventories was reduced to twenty-nine times two, or fifty-eight. These were MECs 116 through 59 in descending order of importance. Class 116 is comprised of those parts coded 1 (major effect) and equipment/component 222 222. From this discussion it can be seen that a method was developed, as operationally feasible, by which the parts in a shipboard inventory could be ranked in order of their importance to the operational readiness of the ship in performing its assigned mission(s).

Although the study indicated a high degree of consistency in the results from the three individual sources of estimation, a study of these results indicated that perhaps more specific criteria were required for evaluations purposes.[1] The Chief, Bureau of Ships, noted certain discrepancies:

1. Component coding

a. Components of equal importance to the ship's mission were assigned to different MEC classes.

b. Minor components were assigned to a higher MEC class than the major component in which it was installed or which it served.

c. Components were assigned to incorrect MEC classes because of the grouping techniques that were used.

d. Components in separate but interdependent systems were assigned differing MEC ratings.

2. Parts coding

a. Parts having an identical functional use in different components were designated as having major importance in one component and minor importance in another.

b. Parts in both categories of part essentiality were often incorrectly designated.

Recognizing that any new systen has its difficulties in the initial implementation stages, certain significant results came forth from the study. It was found that in the equipment/

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[1]U.S., Department of the Navy, Chief, Bureau of Ships, Letter Serial 626A-561 (Washington, D.C., 24 July 1961), p. IVA-4.

component evaluations that only 4% of the components were of the highest military worth, i.e., MEC 116, 11% were considered to be of high worth; i.e., MEC 105-115, and the balance, 85% were of low worth. Similarly in the application of the part evaluation to the above, 4% were in MEC 116; 7% were high worth, i.e., MEC 110-115; 76% were low worth, i.e., MEC 88-106; and 13% were of the lowest military worth, i.e., MEC 59-87.

This study confirmed the previous studies, in that relatively few of the repair parts applicable to a ship's system have high military worth, and conversely, a majority have relatively low essentiality. This enables the ship to pinpoint those items which are vital to operating missions. In effect, it provides the Navy with a realistic and specific definition of insurance items.

The use of Military Essentiality Coding was directed by the Chief of Naval Operations to be implemented fleet-wide.[1] It is significant to note that the implementing directive stated that for systems presently installed in the fleet ALL PARTS WILL HAVE THE ESSENTIALITY OF THE PARENT EQUIPMENT/COMPONENT. In other words, a method is now available to all shipboard supply managers to evaluate the importance of the items of their inventories through a relatively simple coding program for the components listed in their COSAL. Of course, the coding would be done by the technical personnel of the ship,

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[1]Chief of Naval Operations, loc. cit.

but nevertheless, the study described herein indicated that this is a relatively simple task that is not too time-consuming. It is far simpler to code 2,780 components than 51,000 individual parts.

The Optimum COSAL

The so-called Optimum COSAL was the result of the second part of the study which developed military essentiality as a concept. It is the application of military essentiality to the allowance list problem, plus the economic considerations of cost in terms of dollars and storage space. It is the first step toward application of scientific inventory management techniques to the shipboard inventory problem.

The Optimum COSAL Program was a large-scale simulation program utilizing the complete range of potential allowance list candidates which was then applicable to the USS George Washington. The purpose of the simulations was to test various formulations of allowance lists, which in general attempted to maximize the strategic value of shipboard inventories, subject to the aforementioned constraints of dollars and space.[1]

Independent of which particular Optimum COSAL formulation was used, all of them made explicit use of the military essentiality information, price and cube data, technicians' usage estimates or usage data if available, and population data (the number of times a part is installed, and

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[1] Bureau of Supplies and Accounts, Polaris--The Optimum COSAL.

where it is installed). All formulations considered all items simultaneously competing for space and dollar value, independent of controlling inventory control point. All the item characteristics, such as military essentiality, price, and cube, etc., were considered simultaneously for decisions as to stocking. Most important of all is the fact that in deciding whether or not to stock a quantity, specific consideration was given to the item in terms of space and dollar values relative to the expected value of the item for the mission. The early phases of the simulation program tested the manageability of the various formulations as well as their effectiveness. Various assumptions to be utilized in the simulation program were also tested. The final formulations for these simulations were two models, one termed the ordinal model and the other the cardinal model.[1]

The basic technique of both models was to apply protection levels against probability distributions of demand (or usage) in order to arrive at allowance list quantities. They both used the negative binomial distributions of demand sizes, in keeping with analyses of historical demand patterns. Since the cardinal model was finally selected for application to the Fleet Ballistic Missile Submarine allowance list program, the ordinal model need be described but briefly, and that in terms of differences from the cardinal model.

There were two basic differences between the two

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[1] Ibid.

models. The first was in terms of treatment of military essentiality. The ordinal model treated one MEC class as only more (or less) important than another class, while the cardinal model ranked the classes on a relative value or weight assigned as a result of exponential scaling of the MEC categories. The second difference was in the protection level. The ordinal model stipulated a particular protection level for each MEC category, while the cardinal model computed the protection level as a function of price, cube, and weighted military essentiality.

The cardinal model computes a protection level based on the cost in terms of space and dollar value of the item as well as its essentiality. There are three decisions to be made in doing this: choosing a price multiplier or weight to be associated with the unit price of all items (since all items are being considered as simultaneously competing for dollars and space), choosing a cube multiplier, and choosing a scaling factor for exponentially ranking the military essentiality of the various items. It should be mentioned at this point that the protection level is the complement of the risk of stockout during leadtime, which has been described as the tail of the cumulative probability distribution.

The formula for computing the protection level is:[1]

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[1]U.S., Department of the Navy, Special Projects Office, Optimum Techniques for Polaris Logistics Support, The George Washington University Logistics Research Project Report, Serial 11188 (Washington, D.C., 21 December 1962).

$$1 - \frac{\lambda_p P + \lambda_c C}{e^{-x\,(116-MEC)}}$$

Where:

λ_p = Lagrangian price multiplier

λ_c = Lagrangian cube multiplier

P = Unit price

C = Unit cube

e = Naperian number, 2,718

x = exponential scaling constant

Before proceeding further with a discussion of the cardinal model and its operations, an analogy must be made to the basic reorder point formula advocated in the previous chapter. First, the protection level for the cardinal model is the length of the submarine patrol period. It presumes a failure on the first day and an inability to replenish until the end of the patrol. This is procurement leadtime under another guise. Secondly, the Lagrangian multipliers serve the same function as holding cost; however, in the case of the cardinal model the implied holding cost of storage space constraint is explicitly manipulated as a separate function of holding cost. The third point of similarity is that the denominator of the ratio serves the same purpose as shortage cost. Therefore, it can be seen that this is the basic reorder point formula of holding cost to shortage cost, without the latter being stated in monetary form. The exponential scaling of MEC serves to

relate essentiality to performance level on an 0 to 100% scale.

With the ability to change the values of the three constants (the two multipliers and the scaling factor), it is apparent that a multitide of protection levels can be obtained for each item, and a multitude of allowance lists, none of which can be considered as the optimum. After much testing a series of different results was obtained. The one which appeared best to serve the purpose was a rather subjective selection, but was done by experienced officers, and the final selection was made by the Director, Technical Division, Special Projects Office--a Rear Admiral.[1]

The values of the constants used in the cardinal model selected for implementation were .00363 for the price multiplier, .000100 for the cube multiplier, and .15 for the exponential scaling factor.[2] This resulted in an allowance list that had basically the same number of items as the regular COSAL; however, the overall cube requirement was reduced by 16%; overall dollar value of the allowance list was reduced a little, but was basically the same; but the depth, or average quantity of each item was raised by a factor of 4. At the same time, 84% of the cube available for inventory storage was ultimately consumed by material from MEC 100-116, the high essentiality

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[1]Personal interview with Lieutenant Commander D.W. Whelan, SC, United States Navy, Special Assistant to Assistant for Material Support, Technical Division, Special Projects Office, Navy Department, Washington, D.C., March, 1963.

[2]Bureau of Supplies and Accounts, Polaris--The Optimum COSAL.

material, and the dollar value required for stocking of those MECs was more than doubled.[1]

These results are not extraordinary; they are what should be expected from the application of scientific inventory management decisions. Available funds are utilized in a manner that will increase the performance level or operational readiness of the ship. The large amount of emphasis placed on the highest essentiality items is a result of the particular e exponential factor used.

Evaluations of the cardinal model have shown that many items applicable to highly essential equipments or components are backed into MEC 88 because of redundancy or alternatives that are present. Resulting from the computation of protection levels as a function of the three constants (or constant-variables), many of these items are dropped off of the allowance list altogether. To overcome this by changing the slope of the essentiality ranking curve, all items are raised in essentiality through exponential manipulation. This in turn would present other problems of including even more of the high essentiality items than at present, to the further detriment of protection of class 88. To the extent that this problem has been explored so far, the immediate reaction might be that this is all well and good--that this is what the scheme is designed to accomplish. However, one major fault of the Optimum COSAL

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[1] Ibid.
Personal interview with Mr. J. Gumenick, March, 1963.

as exemplified in the cardinal model is that items are dropped from allowance lists through the computation of protection levels before any consideration is made of expected demand for the item.[1] The Chief, Bureau of Ships, was particularly concerned over this, since 93.2% of the BuShips equipments on board fall into classes 88 to 93.[2]

The writer has arrived at the conclusion that the relative ranking of the MEC classes by the exponential scaling factor is as arbitrary as the ranking in the ordinal model, wherein one class was considered as only more or less important than another without considering degree. If time and effort are to be expended in assigning MECs to items susceptible to inclusion in the shipboard inventory, then it seems that a little more effort might be expended in explicitly considering the relative importance of each class and assigning the percentage of essentiality on those explicit considerations. To state the case in another way, a correlation can be made between MEC and performance level; and an explicit statement of performance level can be made on a scale of 0% to 100%. If this is done, there should be little cause for criticism if items are dropped from the allowance list because of low ranking.

The other side of the question, dealing with disregard of potential usage of an item in computing a protection level,

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[1]Personal interviews with Lieutenant Commander D. W. Whelan and Mr. J. Gumenick.

[2]Chief, Bureau of Ships, Letter Ser. 626A0561, p. IV-B-6.

introduces the observation that there is no provision in the Optimum COSAL for variable working stocks as discussed previously. If the allowance list as developed were to be rigidly adhered to, then a working stock level of whatever the patrol period happened to be would be required for all items. Assuming that the patrol is ninety days, it means that at the end of each patrol, ninety days worth of stock for each item experiencing demand would be ordered from the submarine tender. This concept went out of military supply systems with the battleship! It is not efficient, whether you consider it explicitly or implicitly in determination of stock levels. Although economic order quantity quantifications are formal in nature, the concept is one that the newest storekeeper soon adopts implicitly in his operations. More of low-cost items are stocked than of high-cost items. Many variations can be made to the classic EOQ formula expressed in this paper. To apply to the Polaris program it may be necessary to make order quantities in terms of number of patrol periods, although this is not necessary, if the order point considers stocks on hand plus on-order. In that case the full reorder point stock level is carried in the allowance and orders are generated during the cruise as demands require. As a result, more than one order would be placed for the same item upon return from the cruise. The point to be made is that working stocks or economic order quantities provide efficiency in utilization of personnel and operating funds, while the reorder point, including safety stock, provides protection against stockouts during resupply

time.

While this is important from a viewpoint of efficiency, it does not answer the question of items being dropped off the Optimum COSAL before demand is considered, although there is a relationship. Referring again to the concept advanced in the previous chapter, it is noted that the frequency of reorder was proposed as a function of protection required, the point being that the more frequently an item was reordered, the more frequently it was exposed to stockout during leadtime; therefore, the higher degree of protection was required. If EOQ was considered in the Optimum COSAL, the order quantity would be calculated first. Under these circumstances it is possible to have an order quantity calculated for the allowance list, and the reorder point (or protection level) reduced to zero. Under this concept, material would be stocked for on board repair purposes, as a function of efficiency and economy, but the protection level would still reflect operational readiness. The very fact that a quantity was calculated for working stock purposes would make the item more likely to be reflected in the protection level quantities that are calculated.

In any event, by implementation of the Optimum COSAL, great strides are being made in making the shipboard inventory management situation a more efficient one, based on explicitly stated decision rules. No system is perfect in its inception; much work remains to be done, but the very fact that the various problem areas are recognized indicates that there is hope for

their early solution. The next step is to implement the Optimum COSAL program for all ships of the fleet, not just the high priority Fleet Ballistic Missile Submarines.

The Nicol Concept

Some work has already been done in applying these concepts to ships of the Navy, other than in the FBM program. Foremost in their application is the realization that allowance lists as provided at the present time are no more than engineering estimates of requirements, and that little, if any, effort is directed toward revising allowance lists after the original introduction of the equipments into the fleet. The responsibility for determining stock levels, including protection levels, rests with the Supply Officer of the individual ship.

Application of the concepts advocated in this paper can be approached from two points of view: that of the individual ship and that of the type commander. (A type commander has all ships of a similar type, i.e., destroyers, aircraft carriers, etc., within a fleet under his administrative responsibility, which includes funding responsibility.) The points that have been developed in this paper, so far, are directed toward the former, yet there is great potential for the type commander in using these techniques to achieve optimum utilization of the funds available to him for financing operations of his ships.

These funds can be separated into two areas, generally. One element of the appropriation is funds available for day-to-

day operations, which is allocated among the ships of the type for obligation purposes. This is referred to as the operating target amount or OPTAR. The other element consists of those funds available to the type commander for financing the supply overhaul that each ship undergoes every two to three years, concurrently with the regular shipyard overhaul, to correct equipment deficiencies. During this period the materials in the ship's inventory are off-loaded, and using the assistance of shore-based experts, the materials are identified and inventoried, and stock records are corrected to reflect actual balances on hand. These balances are compared with the allowance quantities reflected in the COSAL. Lists are then prepared stating the quantities that are either excess to allowance or deficient therefrom. The problem which faces the type commander is that of determining how many of the shortages can be funded, and which particular items should be procured and to what depth.

The problem can be approached by way of a matrix. Horizontally items are ranked by MEC; vertically they are ranked by dollar value of usage. Obviously, the highest degree of attention should be given to those items with both high usage and high essentiality. By analyzing the shortages appearing on deficiency listings by both money value of usage and degree of essentiality, much more meaningful decisions can be made by the type commander. The stipulation by the Chief of Naval Operations, that in the initial implementation of MEC for

equipments already installed in the fleet, the NEC of the parts will carry the NEC of the parent equipment or component, simplified the problem considerably.

It is not the purpose of this paper to present a detailed recommendation for implementation of the concept, but rather to point a direction which should be taken to improve the efficiency of supply management afloat. To this degree, then, the type commander should utilize the business machine equipments available to his forces during their supply overhaul to perform an analysis of dollar usage. This can quite simply be accomplished as a by-product of other effort that is already required of the crew in processing the off-loaded inventory. Specifically, usage is gathered into EAM card form, and some type of usage analysis is made, ostensibly by the inventory control points with the idea of improving allowance lists. The type commander, however, is more interested in the effectiveness of each individual ship, rather than the allowance list for one particular component. He can, therefore, take the information that is developed by equipments and perform an A-B-C dollar value analysis, as well as a NEC structuring.

In quantifying working stocks it should be noted that NEC has no effect; the primary ingredients are annual demand, price, reorder costs, and holding costs. The writer firmly believes that the concept of economic order quantity (EOQ) has a definite place in afloat supply management. Many people, however, object to this, stating that it is impossible to

determine the parameters of the decision, particularly that of holding cost, for the afloat inventory. Generally, these critics are concerned with the materials handling cost or storage cost of holding, rather than the much more important (in an afloat environment) factors of time preference rate and obsolescence and shelf life. As a matter of fact, EOQ of at least an implicit nature, i.e., stating a certain number of months of supply as an operating level for all items, is used in most instances. The endurance loading concept described in Chapter II is an example. Recalling that the important factor is the ratio of reorder cost to holding cost, it is not too difficult to arrive at a realistic ratio, particularly when it is recognized that the square root of the ratio is a constant to be multiplied times the square root of the variables in the formula. The square root has a mitigating effect on errors of estimation. Quite obviously, because of the enormous fund restraint on the type commander, his holding cost will be high, which will tend to lower the ratio. Commensurately, the effort of reloading storerooms through vertical hatches some six or more decks deep implies a need for less frequent ordering than might otherwise be feasible ashore.

The point is made frequently that the lack of operating funds causes inventories to be reduced to practically nothing. The writer disagrees with this; items with usage history will continue to be used in the future. If these items are not replenished, the ship soon finds itself with equipments out of

commission, an unacceptable state that any commanding officer or type commander would reject. Perhaps some insurance items are let drop from the inventory, but these are generally low essentiality items. In any event, the stock records of the shipboard supply manager must show a reorder quantity or level to which to reorder (the same thing) when a reorder point is reached. The type commander has the ability, during supply overhaul, to project demand history, expressed as averages, for the high and medium usage items, through a computer and compute EOQs (or the quantity Q used previously in this paper) for each of the items, and thereby provide more realistic working stock levels.

Any effort directed toward application of these ideas should commence with the high dollar items that are also highly essential to the operation of the ship. There are not very many items which fit both categories. In both cases, however, the first step is for the performance level index of the various components and equipments to be described, preferably by the type commander's staff. That is to say, the percentage of essentiality should be explicitly stated for the equipments installed on the ship. This is part of the Military Essentiality Program and is being accomplished at the present time.

The first alternative would provide for the high-usage items falling into the highest MEC, i.e., 100% essential to the operation of the ship, being selected out. EOQs would be calculated, then protection levels would be calculated or

computed by varying the shortage cost, until the desired level of protection is obtained. This is the only variable to be manipulated at this point, for the reorder cost and holding cost have already been stated in the computation of working stocks. The estimation of the shortage cost is not difficult, for the type commanders and commanding officer of each ship should be able to state explicitly what level of protection he demands from the shipboard inventory for the highest MSC class, if for no other class. From that point it is a relatively easy matter to put all the cards in the computer, modify the shortage cost used for the highest (or 100%) essential material by the percentage of essentiality that each other item carries. For example, if $5,000 were used as the shortage cost, an item with 10% essentiality would have a shortage cost of $500 used in computing its protection level. Then an allowance of order quantities and order points for each ship undergoing supply overhaul can be computed. It should be noted that this calculation of Q and R should include all items with usage, regardless of what quantity of stock may be on hand at that time. Stocks on hand merely serve to reduce the overall cost; they do not affect the requirements.

After this has been accomplished, and the items with anticipated usage have been protected, it is necessary to look at the items on the COSAL which do not reflect usage on stock records, but which for some reason or other, are missing from the inventory. These are insurance items--those that should be

carried because of the effects of their failure upon the operation of the ship. Using the same information in the stock records, i.e., unit price and allowance quantity, plus the essentiality coding, the items can be structured into a weighted hierarchy of essentiality per dollar, at the same time keeping a record of cumulative cost. At some point in the structure the funding authority (type commander) can cut off the filling of deficiencies with the knowledge of to what degree he has protected the performance level of the particular ship.

From experience it has been noted that many items remain on allowance lists when they have had no usage over a long period of time; these items are really not essential to the performance of the ship. By using the method described, not only can essential shortages be filled, but also many non-essential items can be deleted. This seems to be an obvious objective of the Military Essentiality Program itself.

The other alternative in computing stock levels is to use the computer in a more holistic manner. Instead of setting a protection level for the highest MEC, after computation of working stocks, and structuring shortage costs as a degree of essentiality from that starting point, all items are considered as simultaneously competing for funds, both for working stocks and protection level stocks, somewhat in the same manner as the Optimum COSAL for the FBM program.

This is accomplished by the use of the Monte Carlo

simulation techniques described previously.[1] This would entail projecting random demand simulations against stock levels computed by the use of various parameter constants, primarily the shortage cost. In this respect, the shortage cost would be a basic shortage cost and would be modified for each item as a function of essentiality in the same manner as described above. The result of this operation is to construct a cost-effectiveness curve as in Figure 9. The cost, of course, would be total costs. This would give the type commander a much better prognosis of the results of his decision, and would enable him to make a better selection based on the funds available. The selection made determines the basic shortage cost.

A by-product of either of the alternatives used is to record the parameters of the decisions that were used. This is by far one of the biggest problems faced today in revising allowance lists; the basis for the original decision is not known. In the case of actual demand for a particular part, it is difficult to tell sometimes whether demand is random or is a matter of actually changing demand trends. By recording the parameters of the decisions, the individual ship Supply Officer will be able to revise his computed stock levels after the ship leaves the supply overhaul, as inputs change.

Type commander participation in development of stock levels is highly desirable, if for no reason other than

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[1] Supra, p. 73.

standardization of procedures. The primary benefit to be derived from his participation, however, is that it will provide a structured decision-making rationale for determining stock levels to be maintained within the funding constraints that are so inherent in our operations. A discussion of implementation problems from the shipboard level will provide a better insight into the quantification of parameters.

From the point of view of the individual Supply Officer of a ship, scientific inventory management techniques offer certain advantages. The basic advantage is in the optimization of OPTAR funds to provide consistent policies in protection levels and in freeing the Supply Officer to give attention to the more important problems of the department. The use of these techniques afloat is not new.

USS Hancock Model

Probably the original implementation afloat was aboard the USS Hancock (CVA-19) by Commander Hunter W. Stewart, SC, United States Navy, a former instructor at the Navy Management School, Monterey, California.[1] His introduction of the concept provided certain ground rules for his storekeepers in determining the amount of material to reorder and at what point to submit the reorder. The rules are simple, and are illustrative of the ease with which even minimal application of scientific inventory management can be accomplished in the

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[1]U.S., Department of the Navy, USS Hancock (CVA-19), S-1 Division Instruction 4440.2, 23 September, 1959.

fleet to obtain consistent policies in the use of inventory funds.

The reorder quantity was expressed in terms of a table with five points of entry expressed as annual usage by money value. The results were expressed in terms of months of supply to order. It should be noted that the EOQ formula expressed in this paper is a classic one, and it can be expressed as units, as in this case, months of supply, or money value of procurement. Analysis of the Hancock table reveals that it used an order cost of $10.00 and a holding cost (including all the factors of holding cost) of 20%.

The reorder point was based on the concept advanced by Whitin,[1] in that a Poisson probability distribution was used, and a standard safety level in terms of amount of protection was used for all items in the inventory. This was accomplished by using the normal approximation to the Poisson distribution, in that to arrive at the protection level of 99%, as was desired, the square root of mean demand times leadtime was multiplied by 2.4. The square root of mean demand during leadtime, of course, is the Poisson expression of one standard deviation from the mean. 2.4 standard deviations under the normal probability distribution accounts for 49% of the expected occurrences; this plus the 50% accounted for as equal to and less than the average gives the desired 99%.

Of particular interest in the Hancock model is the fact

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[1] Supra, p. 71.

that only two leadtimes were used. A one-month leadtime was used for all items appearing on the Fleet Issue Load List, and therefore available from underway replenishments, which are scheduled at roughly thirty-day intervals for ships operating with the deployed fleets. Items not on the Fleet Issue Load List were given a three-month leadtime. This is considered to be extremely rational, and it is a point of view that the writer found valid in his own experience. It does much toward formalizing the endurance period expected from ships of the fleet in terms of the functions of inventory: how much to order and when to order it.

A deficiency in the approach, although not an irremedial one, is that it does not consider the concept of military essentiality. This is expected, since it was put into effect before the idea of military essentiality was fully understood, and before much had been published on the subject. Even using this system, however, it is possible for a Supply Officer of a ship to select different protection levels for different items, based on MEC, and to use the number of standard deviations required to give him that protection level. This can be effected quite simply, without the use of any tables of probability distributions, except for a knowledge of the area under the normal probability curve described by any particular number of standard deviations.

USS Coontz Model

The writer applied the concepts of EOQ, variable protection levels, and military essentiality during a recent tour of duty as Supply Officer of the guided missile frigate Coontz (DLG-9). This tour of duty covered the period of pre-commissioning through the first two years of the ship's service with the fleet.

The need for the concept, in fact, was brought home dramatically. In commissioning the ship it was discovered that the new missile equipments, particularly the fire control system, which were the first installed in the fleet, had not been fully provisioned with spare parts, nor had complete allowance lists been developed and furnished to the ship. After many frantic telephone calls and radio messages to obtain non-allowance list parts to repair equipment failures, it was obvious that these parts should be stocked on board. This was no different from any other ship developing repetitive requirements for non-allowance list items, except for the magnitude of the problem, and the importance of the parts to the operational readiness of the ship. Many of the items were considered 100% essential, i.e., the lack of the parts required the return of the ship to port.

In view of this problem, some method was needed on which to base a policy for procuring and stocking these parts. Fortunately, the circular slide rule developed for the Bureau of Supplies and Accounts was available, and the writer was

experienced in its concept.[1] Implementation of the concept of scientific inventory management through this medium, which automatically solved the formulas for Q and R, was largely a matter of trial and error in its initial stages. Because the ship was new, demand history reflected the initial breaking-in period of high demands; therefore, progress had to be slow, particularly since the negative binomial probability distribution in the slide rule allows for the extreme fluctuations in demand that are inherent in military inventories. It did not take long, however, for the features of inventory as described and discussed in this paper to be evidenced. The A-B-C concept of monetary usage was apparent, as was the fact that a small percentage of the items were of extremely high military worth. Of 36,000 items stocked, approximately only 5,000 had usage in a two-year period; and of these, only about 1,000 could be considered as true repetitive demand type items. Even these 1,000 broke down into an A-B-C relationship, as regards use of funds.

Of primary concern in implementing these procedures was the constraint of fund limitations. The OPTAR was provided for operations--for daily maintenance requirements. There was not much left for establishing stock levels for new items. Because of this, and in order to provide for inaccurate prognostications made from limited experience, the holding cost was set at 100%. This accounted for not only a high time

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[1] Clark, Karr, and VanderVeer, op. cit.

[illegible]

[illegible]

preference rate (50%), but also provided for a high obsolescence rate (50%), expected from changes in the allowance lists (deletions) because of design changes in the equipments. Whereas a normal ship receives a new COSAL once each two years as part of supply overhaul, the USS Coontz received four ordnance and four electronic COSALs and three ship's parts allowance lists during the first year in the fleet. This in itself involved a high degree of stock handling apart from the day-to-day operations. The holding cost was varied on individual items, particularly those with short shelf life or higher obsolescence.

The reorder cost was established at $10.00, even though most storerooms were somewhat inaccessible. This was an intuitive judgment based on the writer's experience at the Naval Ordnance Supply Office, where the order cost was originally put at $75.00. An order on board ship did not involve any technical documentation or contract negotiation; it was primarily just typing a requisition from a stock record. In addition, the labor cost of a sailor is much less than that of the civil service. Preciseness in parameter estimation was not a goal; it was recognized from the beginning that errors in estimating either order cost or holding cost were modified by the fact that the results were a function of the square root of the ratio of the two.

The biggest problem was estimation of the shortage cost. This was strictly a trial and error operation, but

interestingly enough, as time progressed one figure kept appearing for most of the high essentiality items that also had repetitive demand. This was $5,000, although on some highly essential items a higher shortage cost was used. The setting of this parameter was based primarily on intuition from having worked with the concept, but also the allowance list provided a certain guide as to whether demands for the items included therein were random fluctuation or valid differences from the allowance list estimation of demand. One aspect of the intuitive judgment was having a "feel" for the amount of stock that would be required to be on hand during leadtime, considering the variations that were possible both in demand and leadtime.

In developing the shortage cost principle for determining consistent protection levels, the writer had not learned the concept of performance levels as an expression of operational readiness. Therefore, more intuitive approaches to military essentiality were used. The concept of military essentiality was used and was expressed in terms of a 0 to 100% scale. The basic shortage cost was set at $5,000 for those items considered as 100% essential to the operation of the ship and not susceptible to redundancy, cannibalization, or jury-rigging. These consisted of many parts applicable to the missile system (missile, launcher, fire control), as well as parts applicable to certain parts of the ship propulsion equipment. Some other items with high, but not the highest essentiality, used on these two system areas were assigned shortage costs of $2,000 and

$1,000. All other parts applying to the hull, machinery, and electrical systems, as well as missile fire control, were assigned a $500 shortage cost. This was done because items could not be segregated for individual study under the conditions under which the ship was operating, and it was considered that a "broad brush" could be applied. Most consumable supplies, such as housekeeping or cleaning supplies, were assigned a shortage cost of $50, and office supplies and other really non-essential supplies were assigned a shortage cost of $5, primarily because of nuisance cost of being out of stock. Conceptually, this can be stated as a shortage cost of $5.00 x 10^n, where n is the essentiality of the item expressed as 0, 1, 2, 3, etc.

Leadtimes for use in the model were the same as used in the USS Hancock model with one small exception. Experience indicated that three months was a realistic approximation of leadtime for an item carried in the supply system, but not on the Fleet Issue Load List. With regard to the latter category of items, experience in the United States Seventh Fleet indicated that a thirty-day re-supply could not always be expected; therefore, as a safety factor, a two-month leadtime was used for items on the Fleet Issue Load List. In addition, items with known procurement difficulties were revised upward.

Ease of implementation of this method was as simple as that experienced in Hancock. A non-rated seaman with relatively little experience in supply management was trained to use the slide rule in a period of a week. Admittedly,

certain restrictions were necessary, but for most items broad guidelines were sufficient.

Certain of the classical results of scientific inventory management were observed. Of primary importance was the fact that in the case of low cost, yet highly essential items, it was possible to buy a large degree of protection with a small investment of funds, more than allowed by the allowance list. This was particularly true in the case of low cost electron tubes, which also experienced high usage. At the same time that a high protection level was being set for these items the EOQ function was setting less frequent order intervals, so that it was possible to devote much more attention to the highly expensive/highly essential items. This type of item was usually reordered each time it was used, and because of the high cost the protection level was less than on other high MEC type items. This was compensated for by more individual attention. There were about twenty items that the Supply Officer exercised personal supervision on their supply management. The high holding cost parameter not only required more frequent re-procurement of high cost items, but at this time these items were also reviewed to determine the validity of the parameter quantifications used in originally establishing order quantities and reorder points.

Certain items were immediately segregated as not being susceptible to scientific inventory management without much introspection. These were the large bulky items, such as wiping

rags, soap powder, paint (which required inflammable stowage), toilet paper, mineograph paper, etc. There were about ten different items. On these, the holding cost was raised to 400% and in a couple of instances, to 1,000%. These figures may appear to be artificially large, but the very fact that they were used in fitting requirements to available space indicates that the decision was structured, and that the available space could be traded off against the importance of the item and probable risk of stockout implied by any particular decision. From this the conclusion was reached that storage space is not a prohibitive factor in stocking material aboard ship. Only a very few of the many items carried cause any space problem. These can be isolated and given separate management attention. The purpose of scientific inventory management is to assist the inventory manager to make his decisions, not to substitute a formula for managerial judgment.

It is to this point that this thesis has been directed. A concept exists which provides the Supply Officer of the individual ship with the ability to structure his decisions regarding inventory management, and thereby make more accurate, more consistent decisions. It gives him the ability to trade off supply effectiveness in support of the equipments in his ship with the funds provided for maintenance of the ship. He can equate his decisions in terms of the operational readiness of his ship.

Implementation is simple. The first step is to analyze

the inventory in terms of dollar value of issues and in terms of military essentiality. The items consuming the majority of funds, and also having high essentiality should be separated for special management attention and analysis. These are the items, few in number, where scientific inventory management techniques will pay large dividends.

Parameter quantification can be accomplished fairly easily. Order cost can be safely established at $10. Holding cost should be put fairly high in the initial implementation stages in order to minimize the degree of error. Economic order quantities can then be calculated for a sample of the items selected for special attention. From this point protection levels, as an element of the reorder point, R, can be computed until a shortage cost is determined for the highest essentiality items. The next step is to obtain the assistance of the technical or line personnel of the ship in determining the essentiality of the high usage value items in terms of performance level of the equipments. With this information other shortage costs can be specified for the items of lesser essentiality as a function of the percentage essentiality times the basic shortage cost calculated for the highest essentiality items. As items decrease in importance it is possible to give less attention to the preciseness of parameter estimation, and to use generalized quantifications. The major advantage of consistent results will still obtain from application of the concepts.

With the parameters quantified, the only thing remaining is to select a type of probability distribution. The most effective method, and simplest, is use of the circular slide rule described.[1] If it is not available the Poisson probability distribution provides the most flexibility with the least knowledge of mathematics or statistics. The important factor in use of any probability distribution is to determine the protection level considering relative military essentiality of the items and order frequency per year.

Although each individual Supply Officer afloat is responsible for the daily management of his inventories, he does not and should not operate in a vacuum. Type commanders have more to realize from the advantages of scientific inventory management, and they should adopt the techniques and assist the ships of their forces to implement them. Through using these techniques during the supply overhaul program each type commander can develop parameter values for force-wide use, as well as deviations for each ship. Parameter preciseness is no more essential in this respect than in any other inventory management environment. Adoption of the concept will provide immediate benefits in a more realistic treatment of the three aspects of supply management: cost of ordering stocks, costs of keeping stocks on hand, and costs of not having stocks when they are required.

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[1] Supra, p. 115.

Implementation of these techniques is directed toward making the best decision possible on the items experiencing repetitive demands, i.e., the ones consuming the funds available for operation of the fleet. These decisions will require less emphasis on low cost/low essentiality items, and will free the Supply Officer to devote his efforts to more effective management of high cost and high essentiality material.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Technological developments of equipments installed in the ships of the United States Navy, since World War II, have increased the complexity of the problems facing the afloat inventory manager. In spite of these complexities, which far surpass those of the civilian inventory, certain analogies can be drawn between civilian inventory management and management of military inventories, both ashore and afloat.

The purpose of inventories is universally one of buying time. They serve to de-couple the end user from the distribution system required to transmit needed materials from manufacturer to the end user. This is of particular importance to ships, for the capability of the Navy to perform its mission in defense of our country is dependent upon its ability to be mobile--to refrain from an absolute dependence on the shore logistics complex. In effect the time that is bought through this de-coupling of dependence on a distribution system is more ready time for weapon systems. This ready time can be measured in terms of operational readiness of the ship--its ability to perform assigned missions.

The problems of inventory management can be generalized into three areas: what to stock, where to stock it, and the

functions of inventory (how much to buy and when to buy it). The functions of inventory are the ones that usually occupy the inventory manager's attention, for they are concerned with the dynamics of inventories. An analysis of these functions reveals that stock levels consist of working stocks and safety stocks. Further analysis of inventories reveals that a small percentage of the items accounts for an overwhelming majority of the dollar demand for the whole inventory, and conversely, the majority of the items accounts for only a small percentage of sales. Military inventories are confounded by a further problem: most items in the inventories feature low issue rates, yet are subject to extreme fluctuations.

Since World War II, the concept of scientific inventory control, as an outgrowth of statistical decision theory used so extensively during the war, has made great advances in its applications to industrial inventories. These techniques have been adopted for use in shore-based military inventories. Progress in implementation of scientific inventory management techniques has been slow. This is due primarily to the fact that most writings on the subject by practitioners of the art (or science, as the case may be) are usually expressed in complex mathematical terms not readily understandable by the non-initiated, the operational personnel who must implement and maintain any inventory management system. Actually, the concept is relatively simple, and with the advent of electronic computing equipment there is no reason why more immediate

implementation is not made throughout inventory systems, be they civilian or military. The possibilities of electronic simulation of the results of decisions are enormous, and they provide an ability to test decisions before implementation.

The concept of scientific inventory control, as in any application of statistical decision theory, requires an explicit consideration or quantification of the interrelationship of the various parameters or inputs involved in an inventory decision. It revolves around that branch of economic decision theory which allows a trade-off of different costs involved in inventory management: the costs of procuring and receiving material; the costs of holding material in store; and the implied penalties arising of not having inventories when they are needed. This approach finds a receptive climate in the Department of Defense at the present time. Particular attention has been given by the hierarchy of management of our armed forces to this economic analysis approach of considering alternative decisions arising from trade-offs and the effectiveness of effort as a function of the cost of that effort.

Aboard ships of the Navy the measurement of operational effectiveness or readiness is vital. This measurement has been translated into the supply management area through the concept of military essentiality coding. This concept has been under study for many years. The results of the study provide the inventory manager afloat with the ability to analyze his

inventory in terms of the importance of the different items to the mission of the ship and to introduce variable stock level decisions.

Military essentiality is translated into an implied shortage penalty for the ship, due to the failure of different equipments. Through it, a realistic inventory protection level can be ascertained for each item aboard ship; however, it is not necessary that each item be rigorously examined to accomplish this. The small percentage of items constituting the largest percentage of dollar issues provides an area of analysis and application of scientific inventory management techniques where benefits of the greatest magnitude will be obtained. Through the introduction of consistent inventory management policies the Supply Officer afloat is able to make better use of his personnel and time through economic ordering principles, and at the same time optimize the use of funds in protecting against stockouts during leadtime by stocking larger quantities of the low cost items and devoting more personal attention to the high cost items. These consistent policies require any inventory manager explicitly to consider the interrelationship of the factors of his decision.

Scientific inventory management techniques have been used successfully aboard ships of the United States Navy. Some have been informal in their introduction, but others, particularly the Optimum COSAL Program, developed for use in the Polaris program, are fully structured and programmed on

electronic data processing equipment. However, the need is apparent for further implementation of the concepts involved. Type commanders in the Navy will receive benefits through the application of these techniques during the supply overhauls that each ship undergoes periodically. Individual shipboard Supply Officers will benefit in their daily inventory management problems. Whatever means of implementation are selected should be done so in a method susceptible to daily use by personnel not trained in statistics or mathematics. Training of personnel in the concepts should be instituted in the Navy Supply Corps School before officers are assigned to the fleet.

There is no reason why such a useful tool for consistent structured decision-making should not be applied to the shipboard inventory management problem. The major deterrent is a lack of understanding of the concepts involved; this can be overcome.

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